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AIRSPACE CONFIGURATION AND SEPARATION EVALUATION
CONFIGURATION AND PROCEDURES
TERMINAL ATC DIGITAL DISPLAY SYSTEM ERRORS, ARTS III

Harry T. Morgan Jr.
Arthur R. Moss

DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA •

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16. Abstract

The major position and separation errors associated with the digital data provided to the radar controller by the Automated Radar Terminal System (ARTS III) are quantitatively assessed to provide the basis for specifying the air traffic control separation minima in ARTS-controlled airspace. The National Aviation Facilities Experimental Center provides a Terminal Automation Test Facility at the Atlantic City Airport with a full complement of technical support facilities and engineering staff; here, an extensive series of live and simulated flight tests were conducted. The methodology, results, and conclusions of this effort are discussed. The results indicate that 99.9 percent of the overall range and azimuth errors can be expected to fall within ±0.16 nmi and ±1.43°, respectively, about their mean errors with a confidence of 90 percent. These errors are less than those generated in trying to read position from the radar displays.

The ARTS III Radar Beacon Tracking Level system reported on herein utilized existing prototype hardware and software as available in early 1974. Many of the capabilities described in this report have since been enhanced by a continuing development program. The reader is encouraged to inquire into the availability of any later reports pertinent to this system.

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PREFACE

Acknowledgement is extended to the following National Aviation Facilities Experimental Center personnel for their contribution to the test and evaluation of the Terminal Air Traffic Control Digital Display System Error, ARTS III:

George Apostolakis	NAFEC Program Manager
Frank Baraccini	Engineering Technician
Donald Bottomley	Flight Test Coordinator
Irving Budoff	Project Pilot
Maurice Cohen	Terminal Automation Specialist
Thomas Grygotis	TATF Systems Engineering
Duane Johnson	TATF Systems Test Coordinator
Robert McCarthy	Terminal Systems Development Programming
Carmen Munafo	Engineering Data Processing
John Riley	Airborne Data Engineer
John Wojciech	Flight Data Analyst

........and to the many NAFEC facility operators whose specialties were diligently applied to achieve the viable and harmonious functioning of this flight test program.

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INTRODUCTION

BACKGROUND.

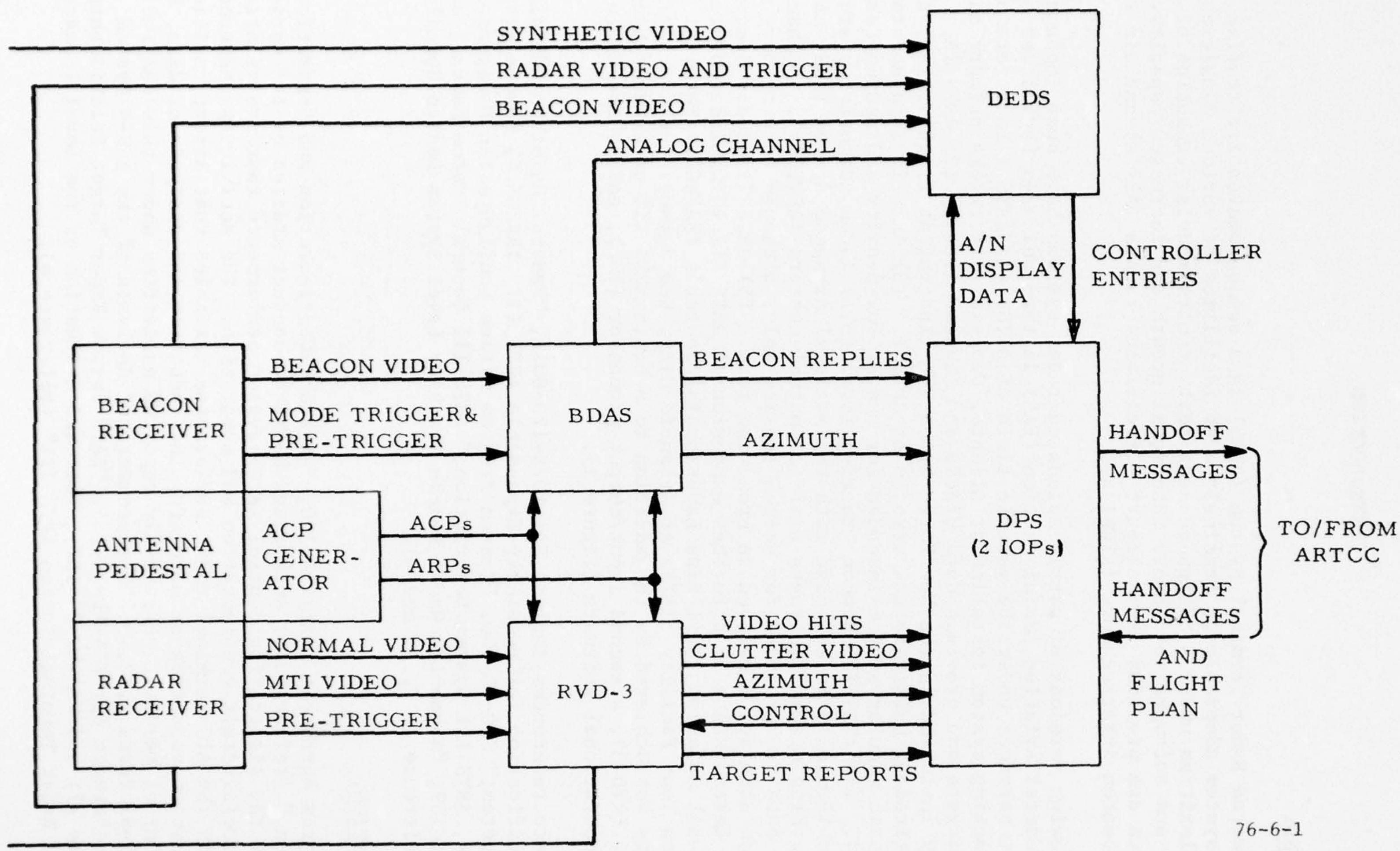
The Automated Radar Terminal System (ARTS) is a semiautomated air traffic control system adaptable to terminal radar facilities of various densities and complexities under a design concept that permits modular expansion of hardware and software to achieve functional growth and increased capacity. Input data are provided from airport surveillance radars (ASR's) and air traffic control beacon interrogators (ATCBI's).

The following versions of partly automated radar systems have been implemented by the Federal Aviation Administration (FAA) in terminal area facilities of the joint services under the generic title of ARTS: (1) ARTS I is a terminal radar tracking system installed at Atlanta, Georgia. It tracks primary and beacon targets and provides data blocks and tabular lists. (2) ARTS IA, presently installed in the New York Common IFR (instrument flight rules) Room, is a multiradar, multiterminal version of ARTS I. (3) ARTS II is a nontracking alphanumeric modular system intended for use at low-density and medium-density terminals. (4) ARTS III Beacon Tracking Level (BTL) is an automated system for major terminals interfacing with the National Airspace System (NAS) enroute radar tracking system air route traffic control centers (ARTCC's). Alphanumeric tracking data are provided for beacon replies only, although both primary radar and beacon data are displayed in broadband form. (5) ARTS III Radar Beacon Tracking Level (RBTL) is a further expansion of ARTS III (BTL) incorporated at the National Aviation Facilities Experimental Center's (NAFEC's) Terminal Automation Test Facility (TATF) at Atlantic City, New Jersey. RBTL tracking capability was achieved by the addition to a basic ARTS III of a Radar Video Digitizer (RVD-3), a second input/output processor (IOP), and by the employment of RBTL operational software (figure 1).

Appropriate references include FAA-TD/S-120-801A, "Federal Aviation Administration Specification for Modularly-Expandable ARTS III (TRACON C) Beacon Tracking Levels System;" SPO-MD-600, "System Program Office Configuration Management Directive, ARTS III System Description;" ARTS III General System Manual; and FAA-RD-74-169, "Augmented Radar Beacon Tracking Level System Design Specification" (reference 1, 2, 3, and 4).

AUTHORIZATION.

Program Area Agreement (PAA) 14-130, "Airspace Configuration and Separation Evaluation," (reference 5) authorized NAFEC to conduct studies of the various facets of the air traffic control (ATC) system performance that are related to airspace/aircraft configuration and separation. The activities thereunder dealt with the ATC terminal radar performance variables that affect position and separation reporting of aircraft, the reduction and analysis of data, and the display of results. Previously reported activities under this PAA include FAA-RD-73-62 Parts 1, 2, 3, "Measurement and Analysis of the ASR-4 System Error" (reference 6); FAA-RD-74-155, "DAIR System Radar Target Relationships" (reference 7); and FAA-RD-73-182, "Test and Evaluation of the Level I Beacon Automated Radar Terminal System ARTS III" (reference 8).



76-6-1

FIGURE 1. SIMPLIFIED BLOCK DIAGRAM OF THE RADAR BEACON TRACKING LEVEL SYSTEM

Activity 142-177-040, reported herein, was initiated by the Terminal Branch, ATC System Division, System Research and Development Service (SRDS) by agreement with the System and Equipment Engineering Branch, Air Traffic Systems Division, NAFEC. The TECHNICAL APPROACH section of the PAA specified that under this activity, a quantitative assessment of the major position and separation digital display data errors would be conducted involving the use of live and simulated aircraft track data throughout the geographic airspace of the terminal area; NAFEC precision tracking equipment and digital simulation were to be employed to determine the various system errors. The EXPECTED PRODUCT is this formal report of the major position and separation error components.

OBJECTIVES.

The technical objectives of Activity 142-177-040, as described in this report, were to quantitatively measure the positional accuracy of the ARTS III digital target reports and tracking data and to analyze the system errors for the purpose of providing a basis for specifying ATC separation minima. Specific criteria to be determined were:

1a. The accuracy to which ARTS III can report aircraft positions,

1b. The accuracy to which ARTS III can predict (track) aircraft successive positions,

1c. The accuracy to which ARTS III can display aircraft positions,

2. The accuracy to which ARTS III can display aircraft separation,

3. The resolution to which ARTS III can report multiple aircraft at various range and azimuth positions about the ASR,

4. The accuracy of the ARTS III mode C altitude reports, and

5. The accuracy of the ARTS III displayed groundspeed.

PRODUCT PLAN.

A Product Plan (reference 9) was prepared by NAFEC as a technical and operational document outlining the effort to be applied in the accomplishment of the PAA. It related in detail the technical approach that was proposed to satisfy the overall objectives. The Product Plan was provided to all support elements at NAFEC as an operational document. It served as the basis for committing resources and for establishing a time frame by which the activity could proceed. The end products to result from this activity were specified in detail to ensure that their form and content were both achievable by support elements and satisfactory to the sponsoring agency.

TEST METHODOLOGY

FACILITIES.

NAFEC test facilities allocated to the activity are extensively described in reference 10, "Technical Facilities at NAFEC," excerpts of which are included as an appendix to this report. The methodology by which these facilities were employed is specified in detail in the Product Plan and is illustrated in a summary form in figure 2.

The equipments primarily used to carry out this activity were as follows:

1. The NAFEC ARTS III RBTL TATF, comprising

    a. Two input/output processors (IOP's),
    b. A beacon data acquisition system (BDAS),
    c. A radar data acquisition system (RDAS) of the RVD-3 model,
    d. Radar Displays with recording cameras,
    e. An RBTL operational program,
    f. A 9300 card processor system,
    g. A UNISERVO VIc magnetic tape subsystem, and
    h. A radar beacon simulator (RBS) programmable target generator,

2. An ASR-5/ATCBI-3 radar facility;

3. An Ampex FR-950 broadband radar video recorder;

4. Two NAFEC Gulfstream I aircraft with mode 3A/C transponder capability;

5. ATC enroute and terminal facilities including the Atlantic City/NAFEC very high frequency omnirange tactical air navigation station (VORTAC);

6. The NAFEC Extended Area Instrumentation Radar (EAIR) facility;

7. The NAFEC Phototheodolite Range facility, herein referred to as Theodolites;

8. An airborne Aircraft Separation Measurement System (ASMS);

9. The NAFEC Range Control Facility, including voice communication and data synchronization radio channels;

10. NAFEC data reduction facilities for photographic and magnetic tape records; and

11. A WANG 700C Advanced Programming Calculator.

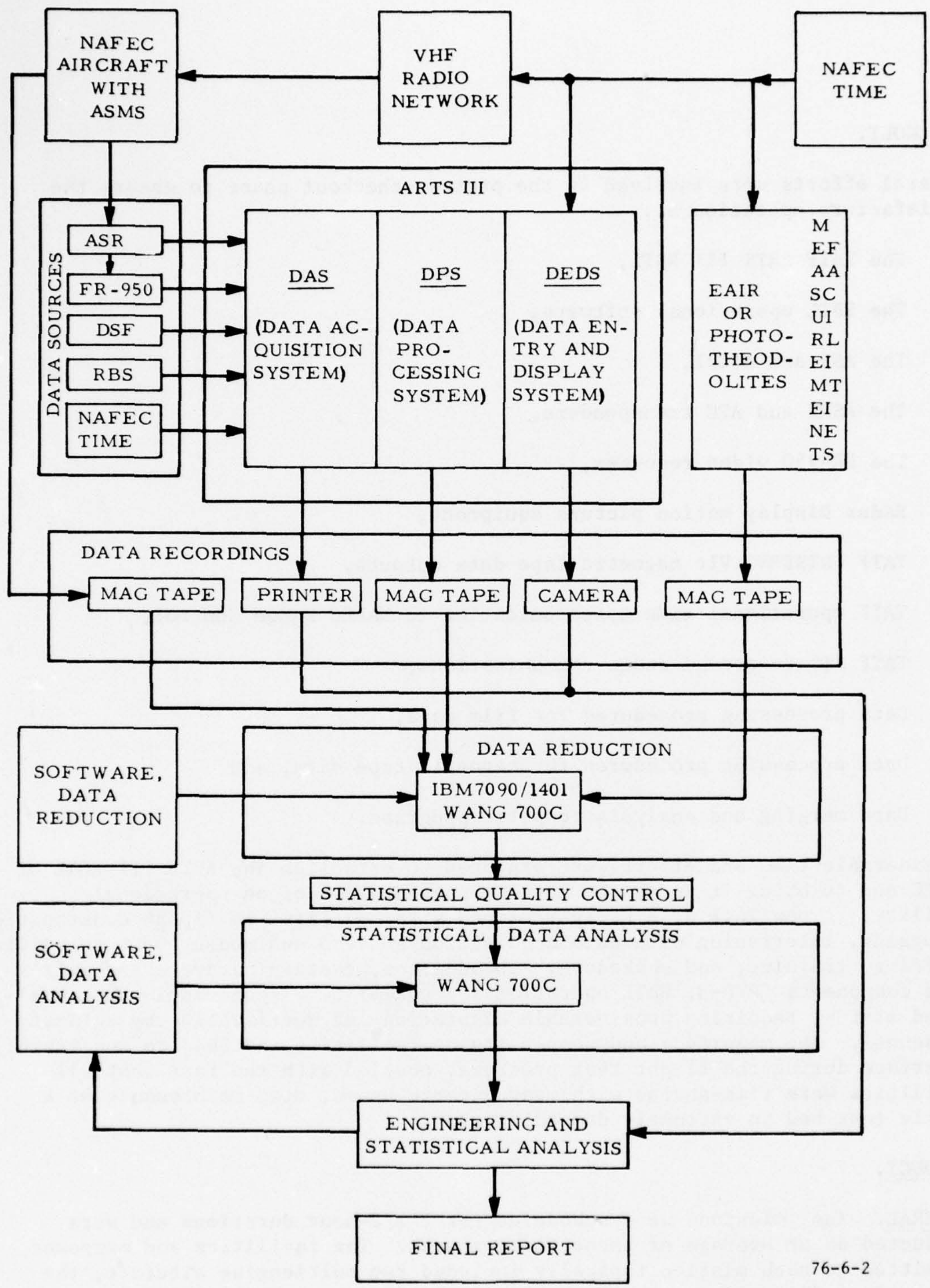


FIGURE 2. SIMPLIFIED NAFEC TEST FACILITY INTERFACE

CHECKOUT.

Several efforts were involved in the pretest checkout phase to ensure the satisfactory operation of:

1. The TATF ARTS III RBTL,
2. The RBTL operational software,
3. The ASR and ATCBI,
4. The ASMS and ATC transponders,
5. The FR-950 video recorder,
6. Radar Display motion picture equipment,
7. TATF UNISERVO VIc magnetic tape data outputs,
8. TATF operational time synchronization to NAFEC Range Control,
9. TATF air-to-ground radio communications,
10. Data processing procedures for film data,
11. Data processing procedures for magnetic tape data, and
12. Data merging and analysis computer programs.

Considerable time and effort were expended to establish the ARTS III RBTL at NAFEC and to bring it up to the level representative of an operational facility. A new TATF at a newly revamped site had first to finish construction, debugging, interfacing with data acquisition sources and measurement facilities, staffing, training, and shakedown. In addition, certain hardware and software components (RVD-3, RBTL operational program) were received in an unqualified status, requiring considerable adaptation and modification by activity personnel. The magnitude and complexity of facilities that had to successfully interface during the flight test programs, coupled with the fact that all facilities were time-shared with many diverse users, made maintenance of a stable test bed an extremely demanding task.

CONDUCT.

GENERAL. Test missions were scheduled for 2 1/2-hour durations and were conducted on an average of three times a week. The facilities and manpower committed to each mission typically included two multiengine aircraft, the EAIR and/or Theodolites, the TATF RBTL ARTS III, the NAFEC ASR-5 facility, an FR-950 recording site, Radar Display photography, a UNISERVO VIc recording system, a test control communications network, and a staff of engineering and support personnel.

Each mission was preceded by a briefing during which support facilities were advised of the particulars of the proposed test; individual roles were coordinated with the overall conduct and expected results. The Product Plan was followed as closely as possible and served as the basis for tying together methodology and objectives.

A premission calibration period was provided during which support and test systems were configured and brought online. Radio communications were utilized to coordinate mission activities in realtime, to ensure readiness of all systems prior to aircraft departure, to overcome contingencies, and to synchronize data collection at the diverse sites.

LIVE FLIGHT TESTS, CONTROL ZONE (Figure 3). Missions were flown with NAFEC Theodolite coverage within the 10-nautical-mile (nmi) radius of the TATF. Two NAFEC aircraft provided target reports performing maneuvers, consisting of inbound, outbound, converging, diverging, and crossover flights.

LIVE FLIGHT TESTS, TRANSITION ZONE (Figure 4). Missions were flown with EAIR as the evaluating facility in the area from 10 to 55 nmi of the TATF. Maneuvers corresponding to those described above were repeated by the NAFEC aircraft. Beyond 25 nmi from NAFEC, flight altitudes were maintained at 10,000 feet or higher to conform to normal approach and departure procedures.

LIVE FLIGHT TEST, AIRCRAFT SEPARATIONS (Figure 5). Missions were flown with a NAFEC ASMS (Hoffman Tactical Air Navigation (TACAN) System) during which two NAFEC aircraft were maintained at various fixed separations from 1/2 to 3 nmi in both trail and abeam formations. In addition, overtake and convergence maneuvers were included.

LIVE FLIGHT TEST, MODE C (Figure 6). One mission in particular was devoted to the collection of altitude position data on a NAFEC aircraft conducting descents in a holding pattern and instrument landing system (ILS) approaches with EAIR as the test standard. Mode C data were recorded as a general rule on all test flights.

LIVE FLIGHT TESTS, TRACKING LEVELS. Selected live flights were recorded at the ASR on an Ampex FR-950 video recorder to provide a means of testing ARTS under various system configurations while utilizing a repeatable data source. It thus became possible to compare the identical aircraft targets with the TATF configured as a BTL ARTS III, then as an RTL ARTS III, then lastly as an RBTL ARTS III. In addition, observations were made of system performance during live flight tests as the BTL mode of operation was switched in and out to permit an assessment of the contribution of the RTL mode to RBTL capability.

SIMULATION FLIGHT TESTS (Figure 7). A series of aircraft target scenarios (figure 8) were programmed and stored on a UNISERVO VIc tape for simulation target generation by the RBS. Flight plans for each target were placed in storage in the ARTS III Data Processing Subsystem (DPS) prior to the start of each test. The test targets were then introduced as programmed on the RBS scenario tapes. Precise specification of target performance and maneuvers, combined with limitless repeatability, provided high confidence levels in results and efficient use of facility resources.

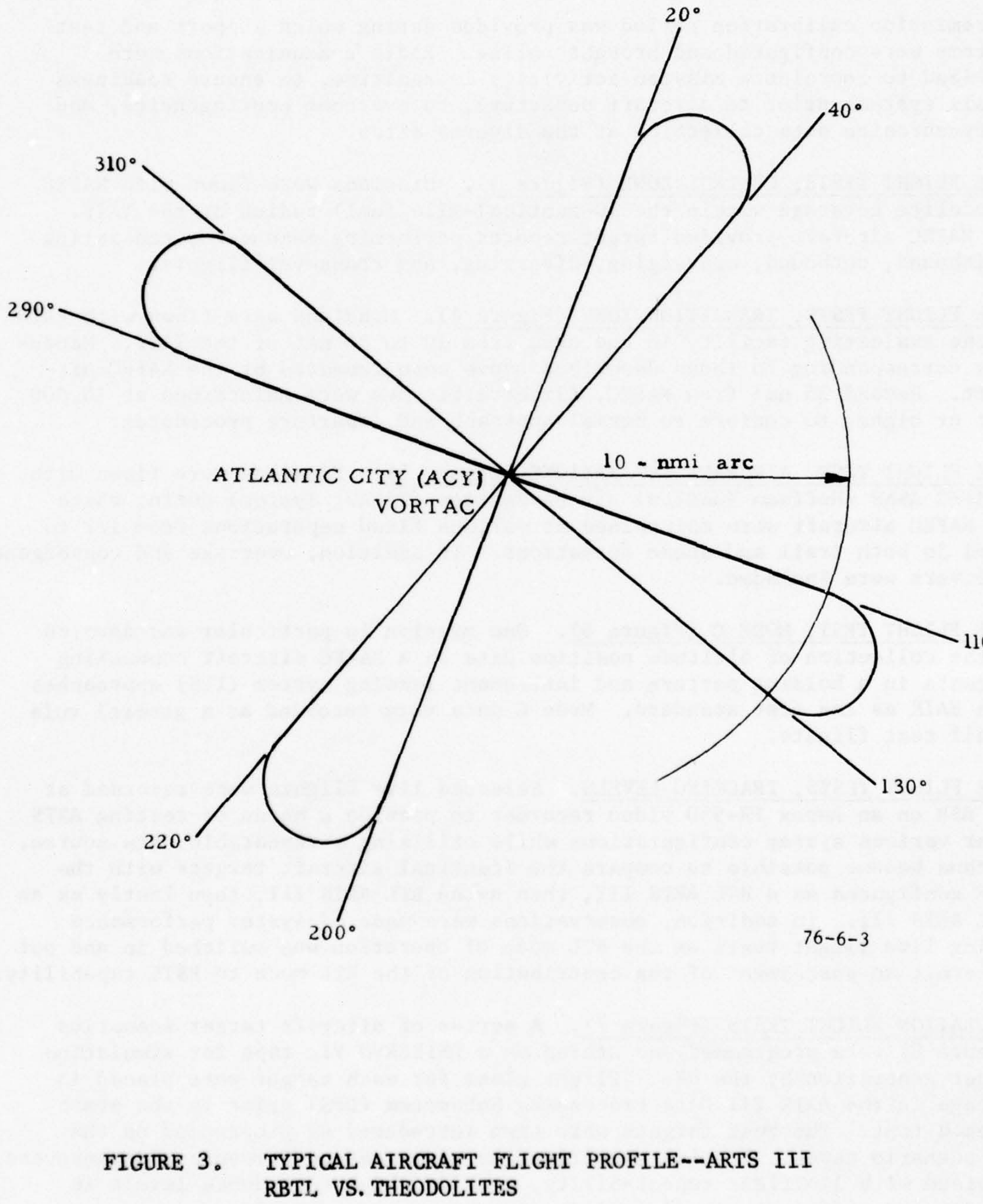


FIGURE 3. TYPICAL AIRCRAFT FLIGHT PROFILE--ARTS III RBTL VS. THEODOLITES

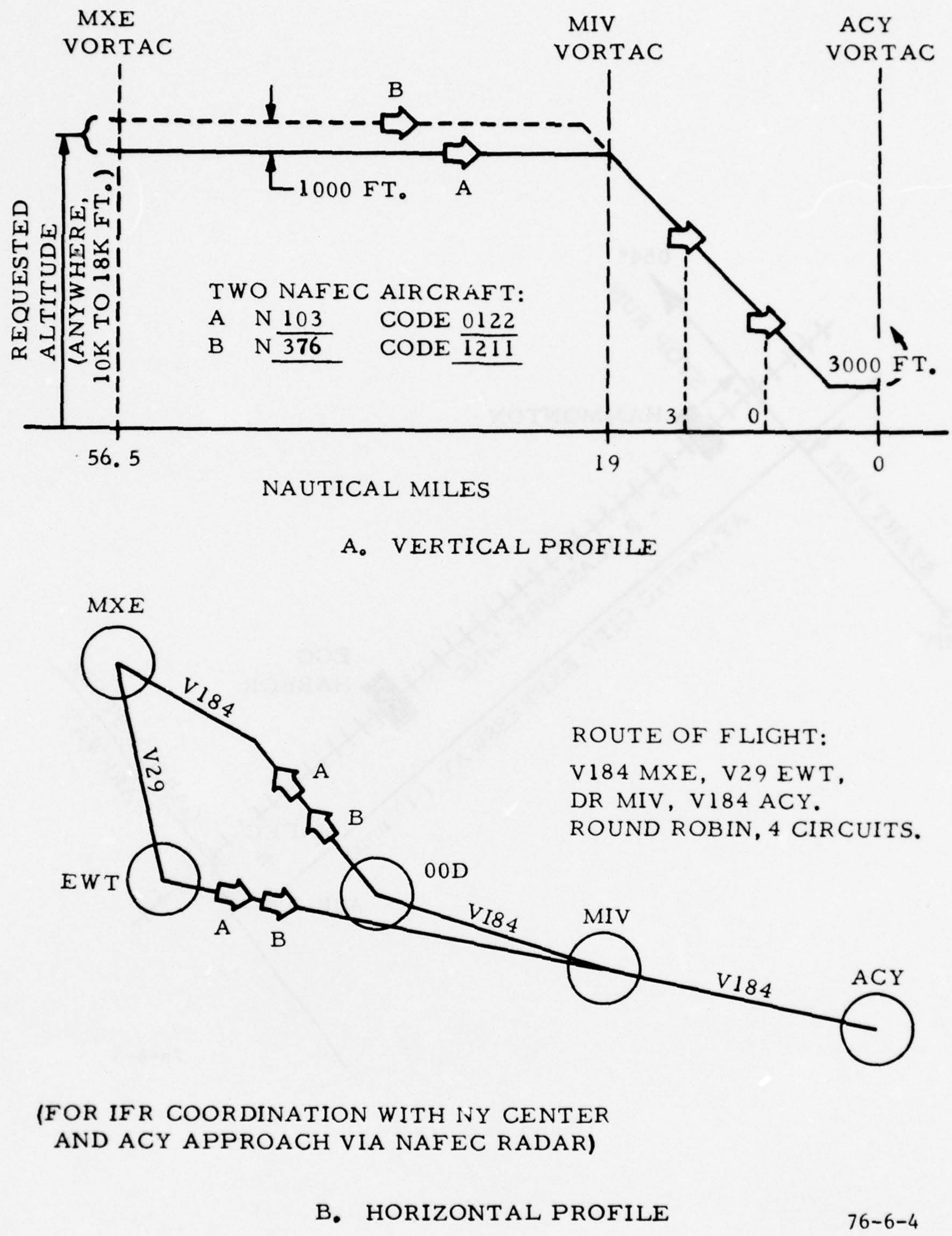


FIGURE 4. TYPICAL AIRCRAFT FLIGHT PROFILE--ARTS III RBTL VS. EAIR

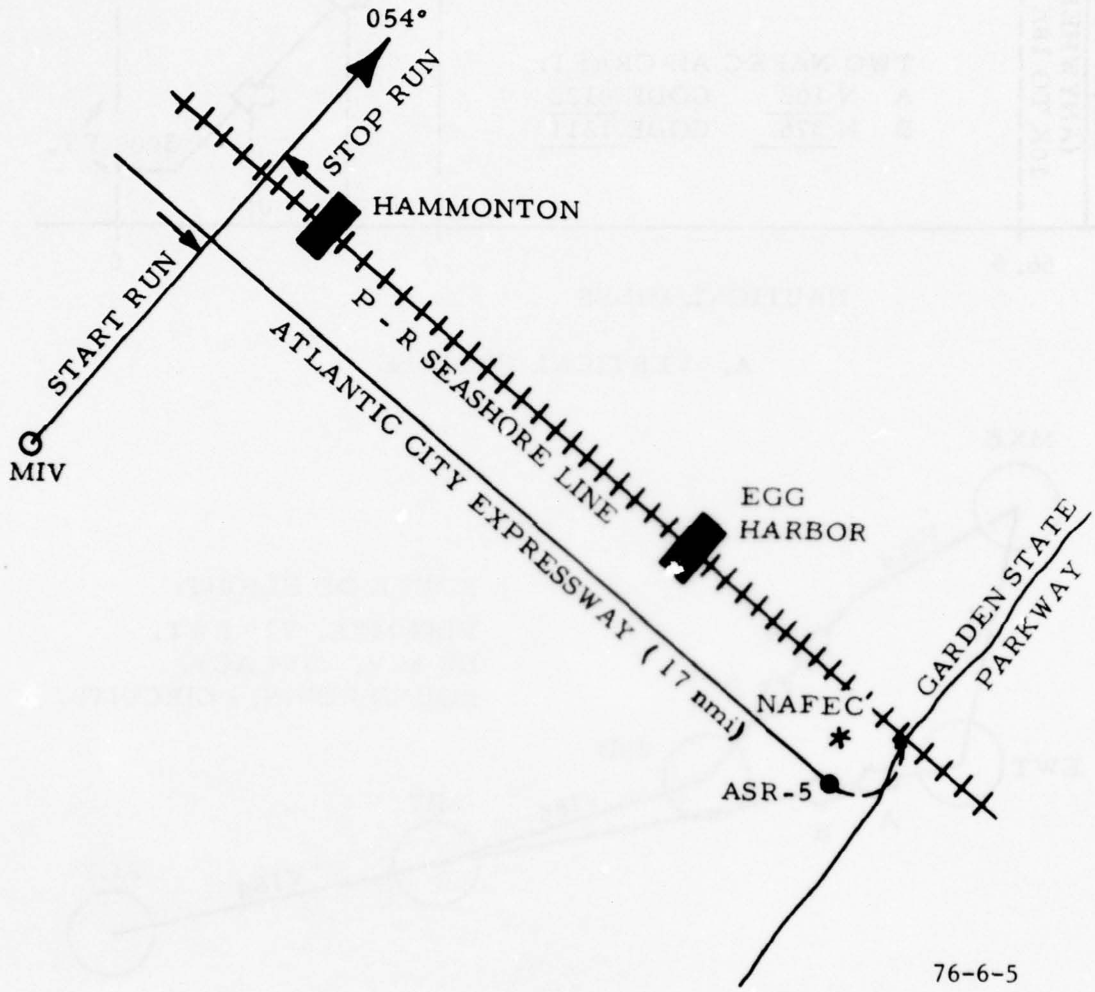


FIGURE 5. AIRCRAFT FLIGHT PROFILE--SEPARATION ERROR EVALUATION

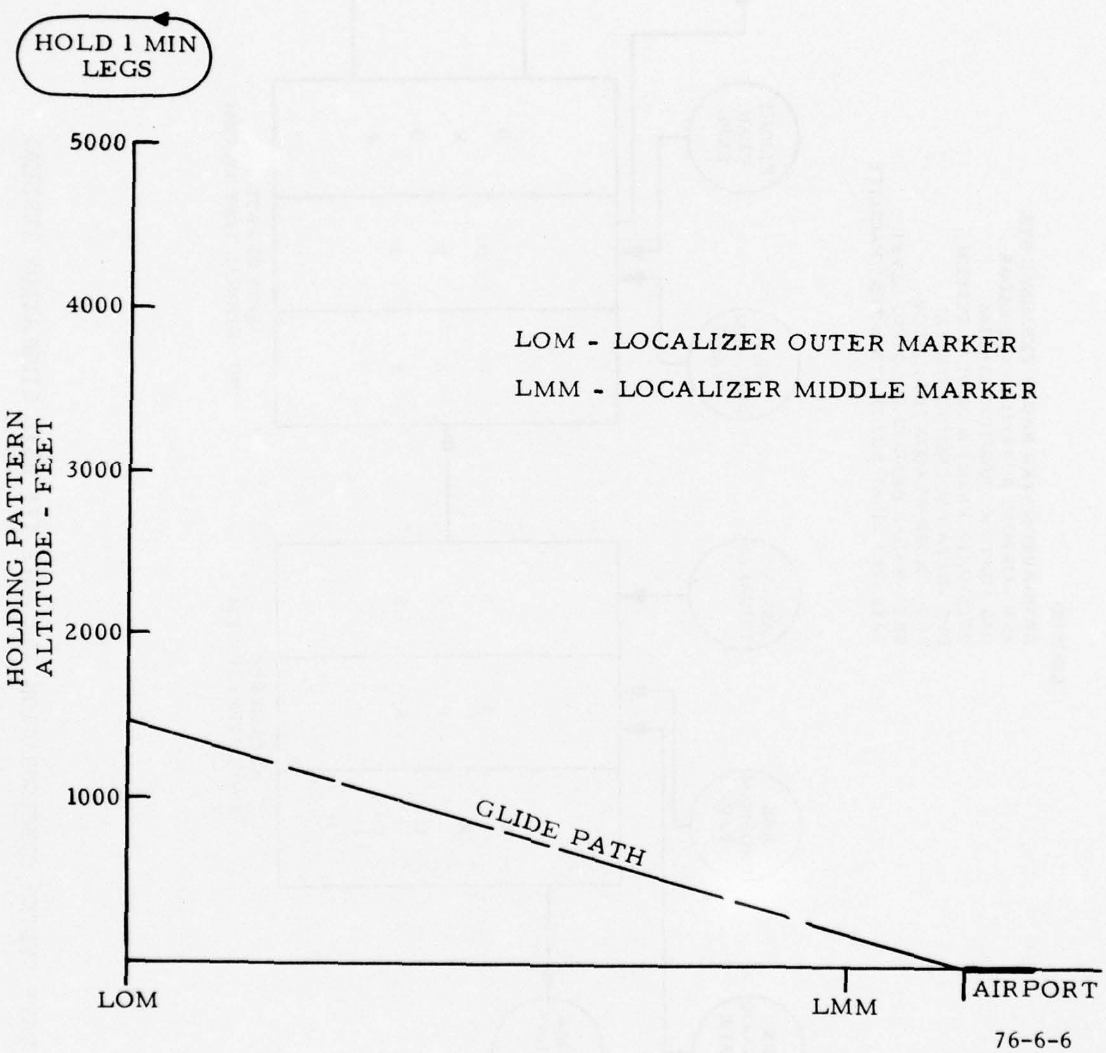


FIGURE 6. AIRCRAFT FLIGHT PROFILE--MODE C EVALUATION

LEGEND

ARTS-AUTOMATED RADAR TERMINAL SYS.
ASR -AIRPORT SURVEILLANCE RADAR
DAS -DATA ACQUISITION SYSTEM
DEDS-DATA ENTRY & DISPLAY SYSTEM
DPS -DATA PROCESSING SYSTEM
RBS -RADAR BEACON SIMULATOR
RBTL-RADAR BEACON TRACKING LEVEL
TATF-TERMINAL AUTOMATION TEST FACILITY

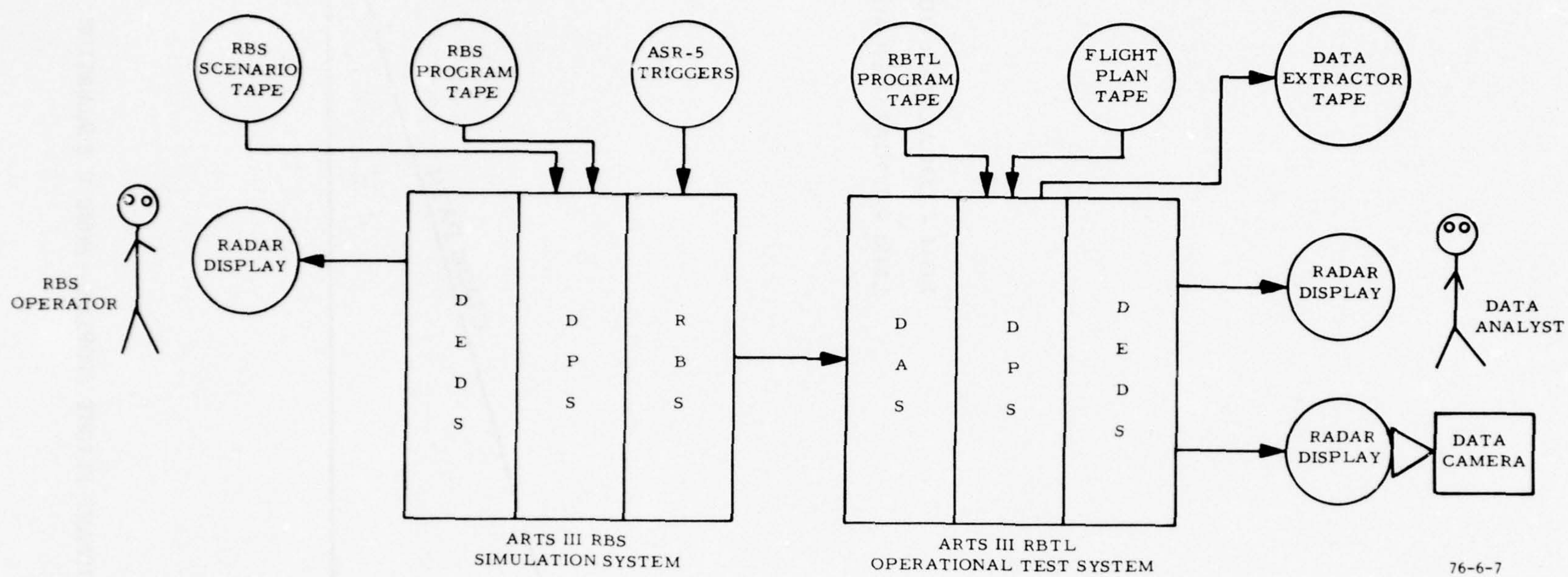


FIGURE 7. TATF SYSTEM CONFIGURATION FOR ARTS III RBTL SIMULATION TESTING

	IDENT	FORMAT
BEACON AND RADAR RESOLUTION TESTS	000	32 targets, 4 on each 45° of azimuth, various trail separations from 1/2 to 2 1/4 nmi, radar and discrete beacon, inbound from 40 nmi.
	001	Same as 000, except radar only.
	002	Same as 000, except separation varies from 2 to 3 3/4 nmi.
	003	30 targets, flying abeam of the origin v225, h180, in trail separation, varying from 1/2 to 2 1/2 nmi, radar and discrete beacon.
	004	Same as 003, except radar only.
	005	Same as 003, except heading is 270°.
	006	Same as 000, except minimum azimuth separation is 5°, some targets radar only.
	007	32 targets separated by 32 ACP's increment of azimuth, inbound from 40 nmi, radar and discrete beacon.
	003	32 targets separated by 5° of azimuth, inbound from 40 nmi, radar and discrete beacon, dB level varies from 0 to 31.
	009	Same as 008, except radar (MTI) only.
CAPACITY TESTS	010	192 targets, ring of 32 duplicated 5 times, radar plus discrete beacon, inbound from 49 nmi.
	011	224 targets, same as 010, except duplicated 6 times.
	012	256 targets, same as 010, except duplicated 7 times.
	013	192 targets, same as 010, except radar only.
	014	224 targets, same as 011, except radar only.
	015	256 targets, same as 012, except radar only.
TURNING TRACK TESTS	016	Nine targets, 188 knots, various turn rates from 0.2 to 3.0°/s, radar and discrete beacon, turn centers about a point 20 nmi out on 360° radial.
	017	Same as 016, except radar only.
	018	Eight targets, 180 knots, various turn rates from 3° to 10°/s, radar and discrete beacon, turn centers about a point 12 nmi out on 360° radial.
	019	Same as 018, except radar only.
	020	One target, accelerating from 60 to 600 knots (45 knots/min), climbing from 2 to 99.9k feet (1,500 ft/min), constant rate of turn of 2°/s, executing a five-turn spiral, radar and discrete beacon.
	021	Same as 020, except radar only.
	022	One target, accelerating from 100 to 600 knots (45 knot/min), climbing from 2 to 99.9k feet (1,500 ft/min), constant rate of turn of 3°/second, executing a five-turn spiral, radar and discrete beacon.
	023	Same as 022, except radar only.
TRACK SWAPS	024	10 targets, converging along 2 and/or 3 tracks at a point 20 nmi west of the origin, in combinations of radar plus beacon and radar only.
LIMIT TRACK SPEEDS	025	20 targets, groups of 5, accelerating from 0 to 1,080 knots, at rates of 45, 75, 120, and 225 knots/min
	026	Same as 025, except radar only.

FIGURE 8. SIMULATION TEST SCENARIOS--RADAR BEACON SIMULATOR

DATA COLLECTION. The results of each mission were recorded to permit offline analysis (figure 2). At the TATF, a UNISERVO VIc magnetic tape of all target reports, track data, and keyboard entries was produced. Simultaneously, a photographic record of the ARTS Radar Display was collected. The output of the ASR, both primary and beacon replies, was selectively recorded on an Ampex FR-950. At each independent measuring facility (Theodolites, EAIR, and the ASMS), recordings were produced on magnetic tape to serve as the standard for the evaluation of the ARTS III RBTL. Observations of system performance were logged online by monitoring a Radar Display position and by two-way radio communications with the test facilities. The digital tape mode of data collection made possible the effective use of computer data reduction to unpack and merge data.

FLIGHT TEST MISSION REPORTS. Subsequent to each mission, a written report was prepared on the results thereof and distributed to all concerned parties (reference 11).

DATA METHODOLOGY (LIVE FLIGHT TESTS)

EDITING.

The editing process consisted of culling selected portions of the live flight data from the total mass of data generated during the flights. The editing was initially done automatically by the data reduction programs. Further editing was then done manually.

AUTOMATIC EDITING. The ARTS III generates a reported and predicted position report on every target encountered during every radar scan. The first level of editing consisted of listing only selected beacon returns, which in this case consisted of the two project aircraft. These data were further edited by selecting only the best quality beacon targets. The selection criteria for reported target positions were strong beacon targets (eight or more hits in the beacon sliding window) with the highest possible mode 3/A and C validity numbers. Multiple targets within the same scan caused by reflections or "ring-around" were eliminated. In the case of the predicted target positions, only those containing the highest track firmness (quality) numbers were selected. No automatic editing was done on radar quality.

MANUAL EDITING. Having culled the highest quality data from the total data mass, the next step was to analyze these errors in terms of the five project objectives outlined in the INTRODUCTION. First, the errors of each day's flights were manually sorted into data groups or population samples representing similar conditions. For example, data were grouped according to whether the flights were along a radial (herein referred to as straight) or a tangential ground track. If straight, a further grouping was whether the aircraft was flying inbound toward the ASR-5 or outbound away from it. Another consideration was the radar quality (RQ) of the target radar and/or beacon return. This radar quality was indicated by a numerical code of RQ0 to RQ7. RQ0 indicated no radar returns at all from the target; hence, this was a beacon-only target. RQ1 was the weakest radar quality, indicating eight or

less hits in the radar sliding window. RQ7 was the strongest radar quality, indicating 19 or more hits in the radar sliding window. Beacon-only targets (RQO), for example, were manually culled from the automatically-edited data and were considered as one group of data, while radar-reinforced beacon (merged) targets showing highest quality radar returns (RQ7) were likewise extracted and considered as another group of data. Each day's flights represented a discrete data grouping, since physical and environmental conditions could conceivably change from day to day.

The procedure in these analyses was to manually select a representative group for each discrete population sample, i.e., one free of measurement or recording errors. Generally, a group of from 20 to 35 was selected. A group of this size was considered large enough to adequately define the required statistical information, yet was small enough to be manageable. The means and standard deviations of the sample group were computed by a WANG 700C program. When 25 or less entries were present in a sample, an outlier search (reference 12, page 640) was first performed on the data. This was another WANG 700C program which looked for inordinately large or small values (outliers) which statistically could not be considered as being representative of the data population. After discarding any outliers, the program computed the mean and standard deviation of the remaining data in the population sample. When the population sample consisted of more than 25 entries, the mean and standard deviation were computed, and a search was made for any data (errors) which were greater than ± 4 standard deviations from the mean. Very few such values were found. In such cases they were discarded, and the mean and standard deviation were recomputed from the remaining data. Radar-only targets were manually picked from the ARTS III printout and processed according to radar quality.

REDUCTION.

The data obtained from the ARTS III, EAIR, Theodolites, and ASMS were reduced by computer programs and presented on program listings. A description of some of these programs and listings is presented in appendix B. The listings contain a substantial amount of information. However, in order to avoid unnecessary complication, only information in the listings which is germane to these investigations was analyzed.

The programs fall into three categories. The first concerns the processing of target report data as reported by the ARTS III. The second concerns the processing of target data as reported by the various measurement systems against which the ARTS III reporting accuracies were checked. (These measurement systems consisted of the Theodolites, the EAIR, and the ASMS). The third category concerns the merging of the same targets as reported simultaneously by the ARTS III and the measurement system, and the determination of the range and azimuth differences or errors.

ARTS III PROGRAMS. Two programs were used to process targets reported by the ARTS III. These were the UNIVAC Extractor Tape Reduction Program and the ARTS III RBTL Unpack Program. A description of each follows.

UNIVAC Extractor Tape Data Reduction Program. This program is part of the software package provided with the ARTS III RBTL. It formats data concerning every radar and beacon target position report generated by the ARTS III as well as all predicted target position messages. This information is recorded on the UNISERVO VIc. A sample of this printout together with a detailed description of the data formats is provided in appendix B1.

The data shown on this listing were the basic ARTS III RBTL target position data which were used for the target report accuracy analyses. These data were used in other programs and listings which are described below. The data on the radar-only targets were used directly from this listing for the radar-only analysis.

ARTS III RBTL Unpack Program. This program provides a listing of selected beacon reported and predicted messages. It operates on the basic ARTS III data in the UNIVAC Extractor Tape Data Reduction Program and lists the selected data, together with appropriate headings. A sample of this printout together with a detailed description of the data formats is provided in appendix B2.

MEASUREMENT SYSTEM PROGRAMS. Programs were used to process target reports received by the EAIR and Theodolites, and also to process and record aircraft separation and bearing readings as measured by the ASMS equipment. A description of each follows.

EAIR Program. This program is incorporated in the NAFEC technical facilities. It translated and rotated the geographical coordinates of the EAIR so that the reported target positions would be referenced using the ASR-5 as the origin rather than the EAIR. The program is designed to record the range and azimuth of a selected beacon target every 0.1 second.

Theodolite Program. This program, likewise a part of the NAFEC technical facilities, is similar to the EAIR program. It recorded the range and azimuth of a selected target as recorded by a pair of Theodolites every 0.1 second. The geographical coordinates of each Theodolite were translated and rotated in such a manner that the range and azimuth of the target would be referenced to the ASR-5 antenna as origin rather than to the Theodolite pair.

ASMS Program. This program provides a printout of the separation and bearing between the two ASMS-equipped aircraft. The separation was in nautical miles, and the bearing was in degrees from one aircraft to the other. These values, along with the time, were printed out each second.

MERGE PROGRAMS. In order to determine the position reporting errors between the ARTS III and the various equipments against which they were compared, it was necessary to compare the range, azimuth, and altitude of a specific

target as reported by the ARTS III with the corresponding values of that specific target as measured by measurement standards (i.e., EAIR or Theodolites). The difference between corresponding values comprised the range, azimuth, or altitude error for that specific target at a specific instant of time. When measuring separation errors between two ASMS-equipped aircraft, the positional difference between the aircraft, as determined by the ARTS III program, was compared against the separation of the aircraft determined directly by the ASMS. The difference between these values comprised the separation error.

To do this, programs were developed at NAFEC to merge the ARTS III data tapes with those of the other equipments. This merging required that corresponding target position reports be referenced to a common origin in space and also to a common instant of time. The geographical coordinates of the ARTS III/ASR-5 antenna, the EAIR antenna, and each of the Theodolites are all different. The ranges, azimuths, and altitudes of an aircraft in space will hence be referenced to the coordinates of the equipment which is measuring it. Since the other equipments were used for comparison purposes with the ARTS III, the coordinates of these other equipments were changed so as to coincide with the ASR-5 antenna, the point of origin of the ARTS III. This was done by translation and rotation of the EAIR and Theodolite geographic coordinates as described above under MEASUREMENT SYSTEM PROGRAMS.

Data time correlation was accomplished in a similar manner; whereby the times of the EAIR, Theodolite, and ASMS target reports were synchronized to those of the corresponding ARTS III target reports.

With target reports from ARTS III and the comparing equipment(s) based on a common time reference and geographic point of origin, position errors were computed by subtracting the range, azimuth, or altitude as reported by the comparing equipment from the corresponding value as reported by the ARTS III.

The merge programs were processed on the IBM 7090 computer. They were used for all the ARTS III target reporting accuracy studies except for the radar-only tests, since the merge programs processed beacon and radar-reinforced beacon targets only. Position errors for the radar-only targets were obtained using the WANG 700C Advanced Programming Calculator. This program was also used for the ARTS III display accuracy investigation. A description of these programs follows.

ARTS III Merge Program. This program was used to list the range, azimuth, and altitude errors for each of two beacon-equipped project aircraft, as well as their separation error. The program could be used for comparison of ARTS III data with either EAIR, Theodolite, or ASMS data. A common printout is used, a sample of which is shown in figure 9. It will be noted that returns are given for almost every radar scan (approximately every 4.68 seconds). The project aircraft are listed as aircraft 1 and aircraft 2. For each aircraft, the range, azimuth, and altitude at the time of a particular radar scan as reported by the ARTS III are provided under the column marked REF, along with the time of the scan. It will be noted that the altitude is given to the nearest hundred feet, since this represents the altitude-resolving capability of the

MERGE ARTS III J-192 WITH EAIR G-50 RUN 5 12/04/74 TARGET DATA

TIME HR MN SEC	AIRCRAFT 1 RANGE REF (NMI)	AIRCRAFT 1 RANGE ERROR (NMI)	AIRCRAFT 1 AZIMUTH REF (DEG)	AIRCRAFT 1 AZIMUTH ERROR (DEG)	AIRCRAFT 1 HEIGHT REF (FT)	AIRCRAFT 1 HEIGHT ERROR (FT)	AIRCRAFT 2 RANGE REF (NMI)	AIRCRAFT 2 RANGE ERROR (NMI)	AIRCRAFT 2 AZIMUTH REF (DEG)	AIRCRAFT 2 AZIMUTH ERROR (DEG)	AIRCRAFT 2 HEIGHT REF (FT)	AIRCRAFT 2 HEIGHT ERROR (FT)	AIRCRAFT SEPARATION REF (NMI)	AIRCRAFT SEPARATION ERROR (NMI)
14 12 11.10	7.88	-0.09	119.18	-0.03	2500	75	6.37	0.	116.02	0.	1900	0	0.	0.
14 12 15.60	7.69	-0.11	118.83	-0.15	2400	19	6.25	0.	115.49	0.	2000	0	0.	0.
14 12 20.50	7.50	-0.12	118.74	0.06	2300	-34	6.12	0.	113.99	0.	2100	0	0.	0.
14 12 25.20	7.31	-0.12	118.56	0.07	2200	-40	6.00	0.	112.06	0.	2200	0	0.	0.
14 12 29.83	7.13	-0.10	119.18	0.39	2200	55	6.00	0.	110.30	0.	2300	0	0.	0.
14 12 34.58	6.94	-0.10	119.97	0.23	2200	-3	6.13	0.	108.58	0.	2400	0	0.	0.
14 12 39.42	6.81	-0.09	121.38	0.26	2300	31	6.32	0.	106.96	0.	2406	0	0.	0.
14 12 44.11	6.75	-0.06	122.96	0.07	2300	44	6.52	0.	105.63	0.	2506	0	0.	0.
14 12 48.80	6.75	-0.03	125.60	0.71	2300	48	6.83	0.	105.38	0.	2613	0	0.	0.
14 12 53.48	6.81	-0.00	127.09	0.14	2300	5	7.07	0.	105.44	0.	2813	0	0.	0.
14 12 58.16	6.88	-0.04	129.55	0.69	2300	25	7.26	0.	106.39	0.	3012	0	0.	0.
14 13 2.87	7.00	-0.07	129.90	-0.62	2300	25	7.52	0.	107.12	0.	3218	0	0.	0.
14 13 7.57	7.25	-0.06	131.66	-0.05	2300	10	7.83	0.	108.15	0.	3512	0	0.	0.
14 13 12.25	7.56	-0.[illegible]	132.23	-0.20	2300	42	8.08	0.	108.94	0.	3706	0	0.	0.
14 13 17.09	7.81	-0.02	132.89	0.17	2300	34	8.33	0.	109.61	0.	3818	0	0.	0.
14 13 21.77	8.13	0.03	132.45	-0.19	2300	21	8.52	0.	109.74	0.	4006	0	0.	0.
14 13 26.45	8.31	-0.06	132.10	-0.23	2300	39	8.77	0.	110.57	0.	4106	0	0.	0.
14 13 35.68	8.88	-0.02	132.01	0.30	2300	26	9.26	0.	110.94	0.	4303	0	0.	0.
14 13 40.52	9.19	0.01	132.01	0.36	2300	37	9.45	0.	111.30	0.	4413	0	0.	0.
14 13 45.20	9.39	-0.09	131.32	0.05	2300	32	9.70	0.	111.74	0.	4606	0	0.	0.
14 13 49.74	9.69	-0.04	131.92	0.04	2300	37	9.95	0.	112.16	0.	4703	0	0.	0.
14 13 54.58	10.00	-0.02	132.10	0.03	2300	55	10.27	0.	112.52	0.	4806	0	0.	0.
14 13 59.13	10.25	-0.06	132.19	-0.12	2300	48	10.51	0.	112.86	0.	4900	0	0.	0.
14 14 3.96	10.56	-0.05	132.63	0.05	2300	69	10.77	0.	113.12	0.	4906	0	0.	0.
14 14 8.64	10.81	-0.09	132.71	-0.08	2300	68	11.02	0.	113.23	0.	5006	0	0.	0.
14 14 13.33	11.13	-0.09	132.98	-0.05	2300	-16	11.27	0.	113.67	0.	5100	0	0.	0.
14 14 18.03	11.44	-0.03	133.07	-0.15	2400	54	11.58	0.	114.08	0.	5106	0	0.	0.
14 14 22.71	11.75	-0.07	133.42	0.01	2400	-14	11.89	0.	114.13	0.	5213	0	0.	0.
14 14 27.41	12.06	-0.06	133.24	-0.38	2500	34	12.08	0.	114.77	0.	5406	0	0.	0.
14 14 32.09	12.38	-0.06	133.68	-0.10	2600	36	12.39	0.	114.54	0.	5506	0	0.	0.
14 14 36.79	12.75	0.02	133.77	-0.20	2600	-18	12.70	0.	114.79	0.	5613	0	0.	0.
14 14 41.48	13.00	-0.05	134.21	0.06	2700	-53	12.95	0.	114.91	0.	5806	0	0.	0.
14 14 46.16	13.31	-0.05	134.21	-0.14	2800	9	13.20	0.	115.37	0.	5913	0	0.	0.
14 14 50.84	13.56	-0.10	134.30	-0.23	2900	72	13.45	0.	114.97	0.	6113	0	0.	0.
14 14 55.54	13.94	-0.03	134.74	0.04	2900	2	13.71	0.	115.15	0.	6306	0	0.	0.
14 15 0.24	14.25	-0.03	134.74	-0.12	3000	34	14.02	0.	115.39	0.	6407	0	0.	0.
14 15 4.92	14.50	-0.09	135.00	-0.04	3100	72	14.33	0.	115.31	0.	6513	0	0.	0.
14 15 9.60	14.81	-0.08	135.13	-0.06	3200	89	14.58	0.	115.24	0.	6706	0	0.	0.
14 15 14.28	15.13	-0.03	135.62	0.20	3200	10	14.83	0.	115.50	0.	6813	0	0.	0.
14 15 18.98	15.44	-0.08	135.62	-0.00	3300	46	15.14	0.	115.65	0.	7006	0	0.	0.
14 15 23.66	15.75	-0.07	135.53	-0.27	3400	28	15.39	0.	115.49	0.	7106	0	0.	0.
14 15 28.35	16.06	-0.07	135.79	-0.19	3500	30	15.64	0.	115.58	0.	7213	0	0.	0.
14 15 33.03	16.38	-0.07	136.05	-0.13	3600	54	15.89	0.	115.65	0.	7406	0	0.	0.
14 15 37.73	16.69	-0.05	136.05	-0.24	3700	55	16.14	0.	115.41	0.	7506	0	0.	0.
14 15 42.43	17.00	-0.05	136.14	-0.37	3800	41	16.39	0.	115.50	0.	7606	0	0.	0.
14 15 47.11	17.31	-0.04	136.32	-0.31	3900	68	16.70	0.	115.66	0.	7706	0	0.	0.
14 15 56.49	17.88	-0.07	136.35	-0.19	4100	84	17.20	0.	115.72	0.	7907	0	0.	0.
14 16 1.17	18.19	-0.06	137.11	-0.04	4200	117	17.46	0.	115.84	0.	8010	0	0.	0.
14 16 10.54	18.75	-0.07	137.37	0.03	4300	43	18.02	0.	115.77	0.	8306	0	0.	0.
14 16 15.23	19.06	[illegible]	137.21	0.44	4400	52	18.27	0.	116.00	0.	8406	0	0.	0.

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FIGURE 9. IBM 1401 PRINTOUT OF ARTS III RBTL/EAIR MERGE PROGRAM

12-pulse mode C transponder, whence the ARTS III obtains its altitude information. The error (ARTS minus EAIR, Theodolite, or ASMS) is displayed under the ERROR column. This comprises the raw error data. Its further analysis will be described in the DATA ANALYSIS section.

WANG 700C Program. This program was used in the two cases where the ARTS III merge program could not be applied, i.e., radar-only error analysis and ARTS III display error analysis. A sample of this printout as applied to the radar-only error analysis is shown in figure 10. Ranges and azimuths for selected radar-only targets were first obtained from the UNIVAC Extractor Tape Data Reduction Program Listing (appendix B1), along with the appropriate sector times. The corresponding EAIR ranges and azimuths were obtained from the EAIR listing, correcting these values by interpolation to correspond to the ARTS III sector times. Using the WANG 700C Advanced Programming Calculator, the time of each scan was entered, followed by the interpolated range and azimuth of the target as reported by the EAIR (position 1) and the ARTS III (position 2). The range and azimuth errors were automatically computed and printed out under the heading POSITION DIFFERENCE.

ANALYSIS.

Having obtained the target report errors by use of either the merge or WANG programs, the next step was to analyze these errors in terms of the five project objectives.

The errors from each discrete data grouping or sample were assumed to be normally distributed. A normal distribution can be defined by two quantities or parameters: the mean, which is the arithmetic average of the errors in the population sample; and the standard deviation, which is a numerical indication of how loosely or closely the population sample errors are clustered about the mean.

If the errors in the data samples were shown to be independent of any other attribute of the data sample, such as range or radar quality, then the mean and standard deviation of the range and azimuth errors were calculated for each such data sample. Statistical tests were then performed between the means and the standard deviations of two or more data samples to determine whether the samples were representative of the same population or whether there was any significant difference between them.

It was found that the samples varied in physical and environmental attributes; for example, the ARTS III/EAIR position accuracy tests were flown on 4 separate days. Each day's flights included inbound and outbound portions. Population samples within each day's inbound and outbound portions were further grouped into beacon-only replies and beacon replies reinforced with high-quality radar returns (merged). Thus, for example, the means and standard deviations obtained on each of the 4 days for the inbound beacon-only target reports were compared to see whether they could be considered as having come from the same population. In some cases, means and/or standard deviations determined to have come from the same population were pooled or combined; in

POSITION 1: EAIR
POSITION 2: ARTS III

DATE: JUNE 4th, 1975
RUN NO: RQ=7 RADAR

TIME	POSITION 1		POSITION 2		POSITION DIFFERENCE	
	RANGE (NMI)	AZIMUTH (DEGREES)	RANGE (NMI)	AZIMUTH (DEGREES)	RANGE (NMI)	AZIMUTH (DEGREES)
10 18 35.03	11.14	321.21	11.13	322.12	-.01	.91
10 18 39.71	10.83	321.25	10.81	322.29	-.02	1.04
10 19 07.71	8.90	320.92	8.88	321.59	-.02	.67
10 23 18.35	6.37	125.62	6.31	127.18	-.06	1.56
10 24 23.64	3.44	98.05	3.38	98.17	-.06	.12
10 36 39.96	6.92	152.07	6.94	153.98	.02	1.91
10 42 11.03	3.28	36.82	3.25	37.53	-.03	.71
10 54 33.62	4.80	193.39	4.81	194.59	.01	1.20
10 57 52.68	7.11	14.51	7.13	15.47	.02	.96
10 58 25.36	6.97	357.95	7.00	358.68	.03	.73
10 58 44.02	7.03	348.59	7.00	349.37	-.03	.78
10 58 57.93	7.27	342.46	7.25	343.13	-.02	.67
10 59 44.80	9.32	338.74	9.31	339.87	-.01	1.13
11 00 03.55	10.02	344.17	10.00	344.97	-.02	.80
11 00 22.45	10.82	348.92	10.81	349.80	-.01	.88
11 00 27.13	11.02	349.99	11.00	350.77	-.02	.78
11 01 04.63	12.96	348.06	12.94	348.75	-.02	.69
11 01 51.35	15.07	341.28	15.13	342.60	.06	1.32
11 13 16.15	6.17	25.65	6.13	25.84	-.04	.19
11 13 25.55	6.30	20.62	6.31	21.27	.01	.65
11 13 34.75	6.35	15.89	6.31	16.70	-.04	.81
11 13 39.43	6.29	13.54	6.25	14.41	-.04	.87
11 13 53.49	6.00	6.48	6.00	7.47	.00	.99
11 13 58.05	5.90	4.19	5.88	5.19	-.02	1.00
11 14 12.11	5.72	356.81	5.69	357.89	-.03	1.08

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FIGURE 10. POSITION ERROR LISTING--ARTS III RBTL VS. EAIR, RADAR-ONLY

other cases, the tests were used for comparison purposes between the population samples with differing attributes. For example, two population samples differing in that one consisted of beacon-only replies while the other consisted of merged replies could be tested to see whether the radar reinforcement had any significant effect on the magnitude (mean) or spread (standard deviation) of the range or azimuth errors. When data samples were pooled or combined, the overall sample sizes were increased from 20 or 30 up to as high as 407.

The various tests that were performed are described in appendix C of this report. The tests and terminology thereof can also be found in any standard textbook of statistics. In comparing data samples, corresponding standard deviations would be compared first. If the standard deviations compared, then the corresponding means were compared. If the standard deviations did not compare, the corresponding data samples were not considered as having come from the same population, and the means therefore could not be compared. In that case, the interval over which the actual range or azimuth errors occurred was determined.

SIGNIFICANCE LEVELS. The closer together corresponding means and standard deviations are, the greater is the likelihood that they are from the same population. This likelihood is numerically expressed by the significance level. A significance level of .05 means that if sampling is done from the same underlying statistical distribution, only 5 percent of all possible mean or standard deviation differences will be larger than those calculated using values from statistical tables. If the observed difference is less than the theoretical value, then it can be assumed that the difference observed was due to chance alone. If the observed difference is greater than the theoretical value, then it can be concluded that something other than chance variations caused the difference and, in fact, there are two distributions or populations instead of just one.

A 5-percent significance level is a tighter or better fit than a 1-percent significance level. Generally, a .05 level of significance will be assumed, and where a test of comparison shows no significant difference in the means or standard deviations at the .05 level, the table will indicate NO SIGNIFICANT DIFFERENCE. Where a comparison is found to be significant at the .05 level, but not significant at the .01 level, the table will indicate NO SIGNIFICANT DIFFERENCE (.01). Where the comparison was found to be significant at the .01 level, the table will indicate SIGNIFICANT DIFFERENCE.

TOLERANCE LIMITS. The various accuracies to which the technical objectives are addressed may be interpreted as being the tolerance limits within which a certain proportion of the individual errors can be expected to lie with a certain statistical confidence. For this evaluation, these limits correspond to a proportion of 99.9 percent and a confidence of 90 percent (reference 9, page 17). These accuracies are equal to plus or minus a certain number, K, of standard deviations about the mean. The factor K depends on the sample size investigated. For the limits and probability used herein, this factor K varies from a value of 4.3 for a sample size of 20 to a value of 3.291 for an infinite sample size.

The individual errors (hence the means) are influenced by biases which can be physically compensated for by calibration, adjustment, etc. These biases do not influence the standard deviations, hence the accuracies will be stated as a function (K) of standard deviations about a mean value which, by physical adjustment, can be minimized, if not actually eliminated. Where it was possible to pool or combine standard deviations, that value was used in the accuracy determinations. Where it was not possible to pool the standard deviations, the largest value was used to provide the most conservative accuracy determination. The results of the analysis of the data in terms of the five project objectives follows.

1. AIRCRAFT POSITION REPORTING, PREDICTING, AND DISPLAYING ACCURACY. This objective actually encompasses three performance characteristics of the ARTS III: (1) the accuracy with which it can REPORT a digitized radar or beacon aircraft target, (2) the accuracy with which it can PREDICT or track the position of the aircraft, and (3) the accuracy with which it can DISPLAY a symbol representing that aircraft on a radar scope or console. Each of these characteristics will be discussed separately.

a. Aircraft Position REPORTING Accuracy. This characteristic was measured for distances between 3 and 10 nmi from the ASR-5 by means of the two ARTS/Theodolite flights on November 6 and 8, 1974. For distances between 10 and 40 nmi from the ASR-5, the four ARTS/EAIR flights of November 18, 25, 27, and December 4, 1974, were used. The straight-line (inbound and outbound) portions of these flights were used. The position errors (range and azimuth) were measured for both beacon-only and merged (beacon reinforced with good-quality radar) targets. Two project aircraft were utilized for the ARTS/Theodolite runs, while only one aircraft was recorded in the ARTS/EAIR flights.

A linear regression analysis (appendix C1) was performed on each of the range and azimuth groupings of the ARTS/EAIR flights to determine if there was a linear relationship between the values of the errors and the aircraft range. This analysis indicated little or no correlation of position errors with range; hence, the position errors in each data group were considered independent of range. Means and standard deviations were accordingly computed for each data grouping of the ARTS/Theodolite as well as the ARTS/EAIR flights (appendixes D1 and D2).

A check was made of the underlying statistical distribution of the errors in each range and azimuth data grouping of the above flights. These distributions were shown to be generally normal or Gaussian. Frequency distributions of the range and azimuth errors occurring on December 4, 1974, for each of the two target types are shown in figures 11 and 12.

In addition to the straight-line flight analyses described above, position errors for the tangential portions (beyond 40 nmi) of the December 4, 1974, ARTS/EAIR flights were analysed. The tangential portion connected the outbound and inbound radials, occurring somewhat beyond 40 nmi from the ASR-5. Finally, position errors were analysed for radar-only targets using the ARTS/EAIR flight of June 4, 1975 (figure 5). The June 4, 1975, ARTS/EAIR NAFEC-Hammonton flight was used for the radar-only target report comparison because

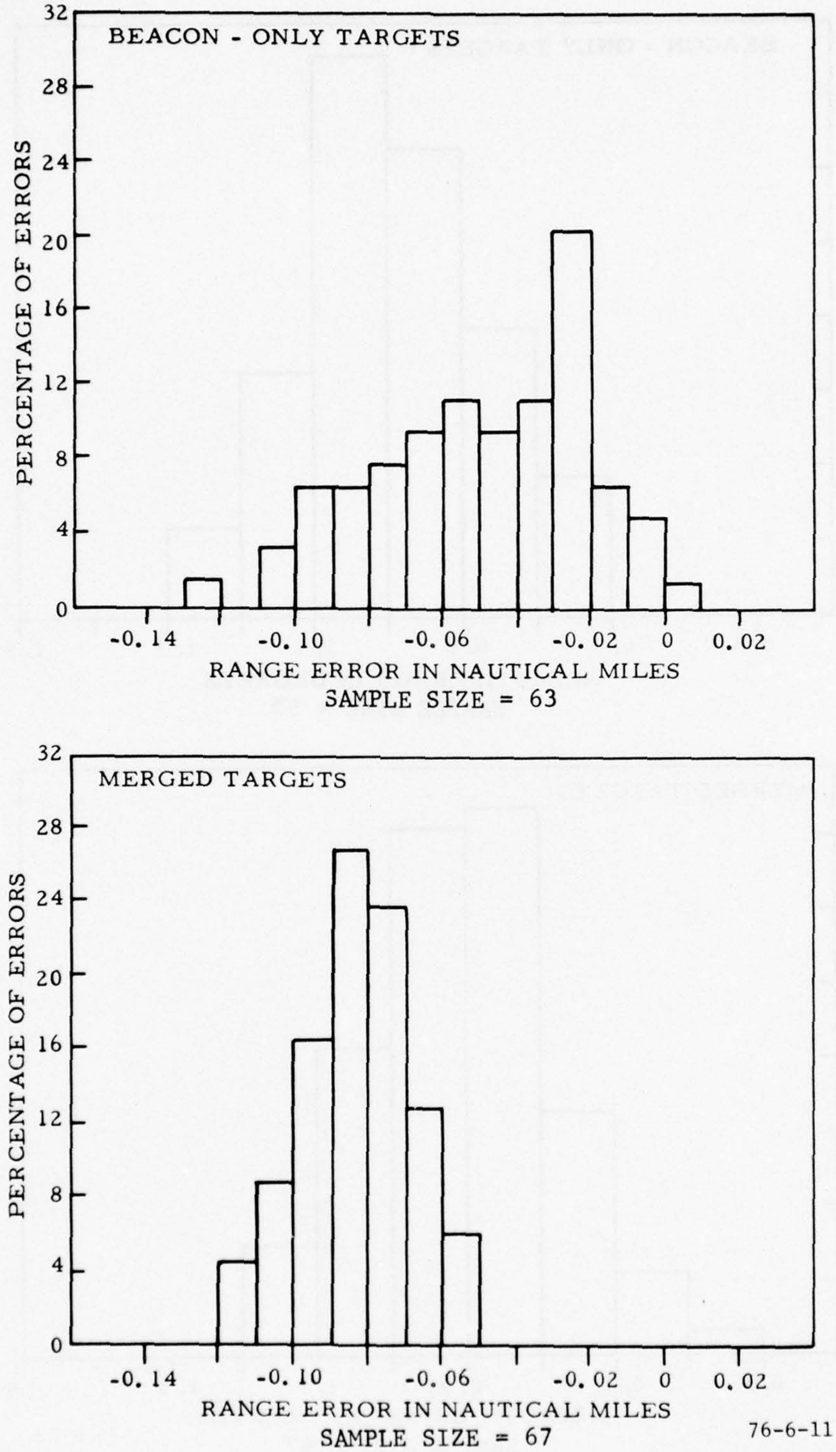

FIGURE 11. DISTRIBUTION OF ARTS III RBTL RANGE ERRORS

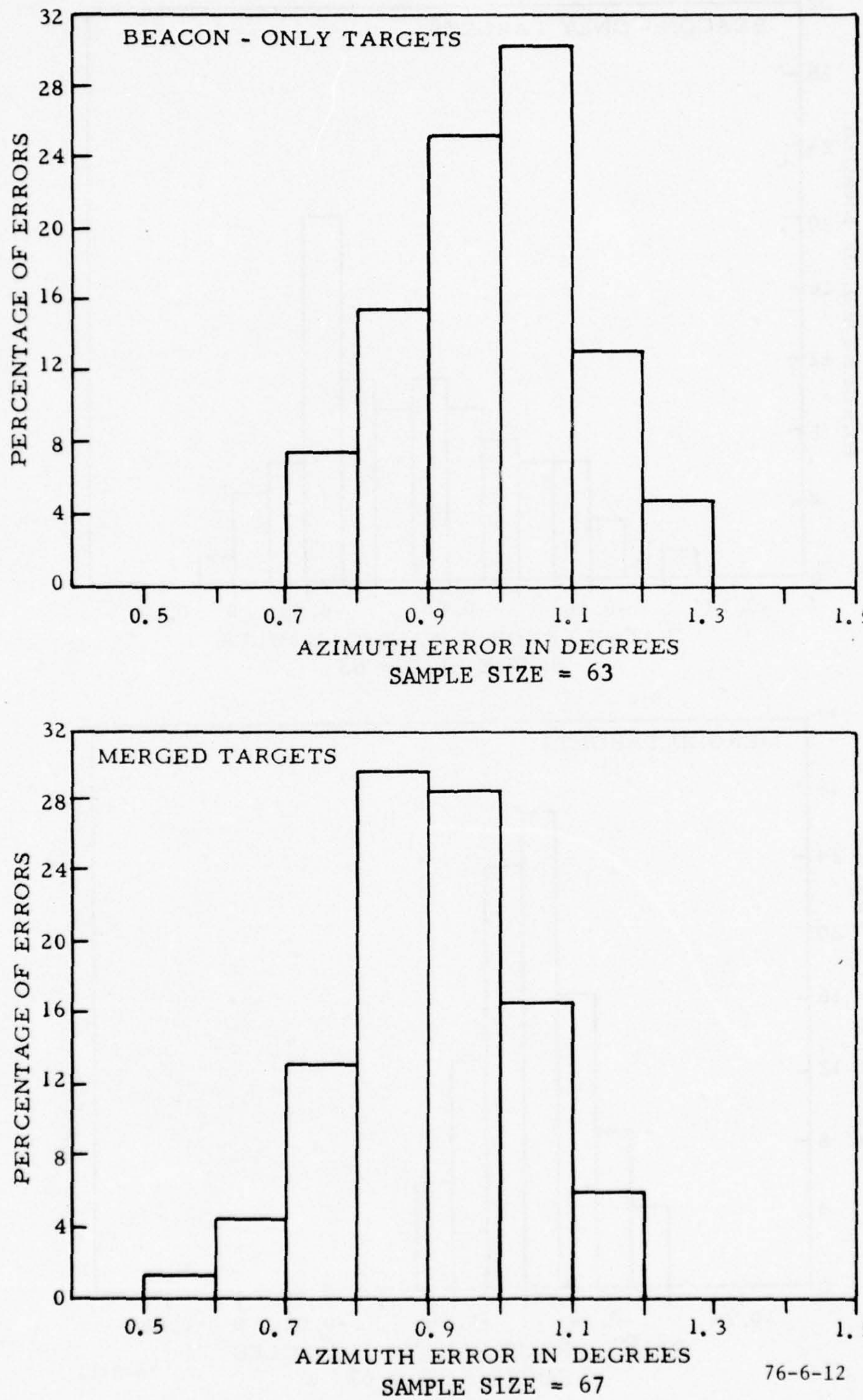

FIGURE 12. DISTRIBUTION OF ARTS III RBTL AZIMUTH ERRORS

beacon replies were not received from one of the participating aircraft, its transponder being intentionally turned OFF. Using the ARTS III computer printout of all ARTS III target reports, ranges and azimuths of the radar-only target reports were obtained and compared with the corresponding values obtained from the EAIR computer printout. The radar quality (RQ-1 through 7) was also recorded, and a simple linear regression analysis was then performed to see if there was any correlation between radar quality and the magnitude of range and azimuth errors for the radar-only targets. This analysis showed that there was only a fair degree of negative correlation between radar quality and range error, and virtually no correlation for azimuth errors. On the basis of these results, error values for each data grouping were lumped together without regard to radar quality. Means and standard deviations were computed for each grouping, which, in this case, consisted of one group of radar-only targets with radar quality (RQ=7) and one group of merged targets (beacon reinforced with RQ=7 radar).

b. Aircraft Position PREDICTING Accuracy. This characteristic was measured by means of the December 4, 1974, ARTS/EAIR flight. The predicted aircraft positions were obtained from the track messages printed out via the ARTS III RBTL Unpack program (appendix B2). These were obtained for both straight (inbound and outbound) and tangential flight attitudes. Radar quality was not considered in this analysis, and only track messages of the highest degree of firmness (39) (appendix B1-3) were used. Each predicted position error consisted of the difference between the track message range or azimuth value and the corresponding target position value as reported by the EAIR (i.e., ARTS III-predicted position minus EAIR-reported position).

A simple linear regression analysis was performed on the straight-flight groupings to determine if there was any correlation between range and the predicted position errors. Little or no correlation was shown; therefore, the error values in each grouping were lumped together without regard to range (appendix D3). These analyses were performed on the inbound and outbound groupings for both range and azimuth.

c. Aircraft DISPLAYING Accuracy. This characteristic was measured by means of flights conducted on March 8, 1974. A range of 14 nmi was used. The displayed position of the target was obtained from radar display photographs using the Telereadex machine (figure D-7 of appendix D4). The corresponding reported position was obtained by an unpack program similar to that described in appendix B2. The error was the displayed minus reported position in range or azimuth. A linear regression analysis was performed to see if there was any correlation between the display errors and the distance of the symbol from the display center. This analysis showed that the range and azimuth errors were correlated with the distance of the symbol from the display center (appendix D4).

2. AIRCRAFT SEPARATION REPORTING ACCURACY. This characteristic was measured using ARTS III versus ASMS and ARTS III versus Theodolites. Two project aircraft were used in each method. The ARTS/ASMS flights were performed on May 30 and June 2, 1975, using the NAFEC-Hammonton flight pattern (figure 5). The ARTS/Theodolite flights, conducted on November 6 and 8, 1974, were the same flights used for the target reporting accuracy tests.

The ARTS III target report range, azimuth, and altitude data from each aircraft were used to calculate the slant range separation between them. These separations were compared to the corresponding separations as reported by the ASMS equipments for each of the various fixed and variable separations. The difference in these separations (ARTS minus ASMS) comprised the separation errors.

The fixed separations consisted of 0.5-, 1.0-, 1.5-, and 2.0-nmi lateral (abeam) separations and 0.5- and 1.5-nmi longitudinal (in trail) separations. The variable separations consisted of linear overtakes and angular convergences with separations between ± 3.5 nmi.

For the ARTS/Theodolite flights, a computer program provided a listing of separation in nautical miles between the two aircraft at a given point in time, as well as the difference, or error, in the aircraft separation as reported by the Theodolites compared with the corresponding separation as reported by the ARTS III (reference). An analysis of these separation errors was made for each of the four quadrants for each of the 2 days.

3. <u>AIRCRAFT RESOLUTION ABILITY</u>. This characteristic was measured by means of the May 30, 1975, ARTS/ASMS flight in which the two project aircraft utilized the NAFEC-Hammonton pattern of figure 5. Resolution ability was measured in terms of the percentage of the total number of observed radar scans where reports on both project aircraft were generated each scan by the ARTS III for any given range or azimuth increment. Round reliability (blip/scan) variations, if any, were ignored.

Measurement of range resolution was accomplished by utilizing the overtake flights. The actual separations of the two aircraft were obtained from the ASMS printout. Resolution percentages were determined for 1/2-nmi increments of range separations up to 3.5 nmi. Only those scans where the azimuth separation of the aircraft was within the ATCBI-3 antenna beamwidth (4.5°) were considered in the range resolution measurements.

Measurement of azimuth resolution was accomplished by utilizing all scans where the slant range of each aircraft was at least 3 nmi from the ASR-5 and where the difference in slant ranges did not exceed 0.25 nmi. Resolution percentages were determined for 1° increments of azimuth separations from 0° to 10°.

4. <u>MODE C ALTITUDE REPORTING ACCURACY</u>. This characteristic was measured by means of the November 6, 1974, ARTS/Theodolite flights. The ARTS III extracts and decodes the mode C altitude, which is encoded in 100-foot increments.

5. <u>DISPLAYED GROUNDSPEED ACCURACY</u>. This characteristic was measured by means of the November 8, 1974, ARTS/Theodolite flight. The comparisons were made for each full minute common to both ARTS and Theodolite data recordings which had no reversal of direction in either the x or y direction. The average velocity for the ARTS was computed by averaging the track velocities printed out within the full minute concerned. These track velocities were generally printed out each antenna scan, and varied between 10 and 13 per minute. The average velocity for the Theodolite was obtained by subtracting the x and y positions of the aircraft in feet at the end of the minute concerned from the corresponding positions at the beginning of the minute. This was then converted into velocity.

RESULTS (LIVE FLIGHT TESTS)

AIRCRAFT POSITION REPORTING ACCURACY.

RANGE ACCURACY--STRAIGHT FLIGHT--ARTS/EAIR. Table 1 shows the means and standard deviations of the range errors for each of the two target types for each of the 4 days of the ARTS/EAIR tests. The means were obtained by averaging inbound and outbound means as described above. The inbound and outbound standard deviations for each target type for each day were statistically compared by means of an F-test (appendix C2). When this test showed no significant differences between them, the inbound and outbound standard deviations for the day and target type concerned were combined or pooled. This was the prevailing condition for seven of the eight day/target-type combinations shown in table 1. The one combination where significant differences were shown was for merged targets on December 4, 1974. For this case, the overall standard deviation was computed for all 67 range error values after inbound-outbound biases had been averaged out.

The four pooled daily standard deviations for each target type were now tested by means of Bartlett's test for homogeneity of variances (appendix C3). All four daily standard deviations for the beacon-only targets passed the test at

TABLE 1. RANGE ERROR SUMMARIES--ARTS III RBTL VERSUS EAIR DURING STRAIGHT FLIGHT

	Beacon-Only Targets			Merged Targets		
Test Date (1974)	N	Mean (nmi)	Standard Deviation (nmi)	N	Mean (nmi)	Standard Deviation (nmi)
11/18	62	0.16	.030	63	0.02	0.028
11/25	61	-.02	.029	64	-.06	.020
11/27	49	-.01	.020	88	-.06	.022
12/04	63	-.05	.029	67	-.08	.015
COMBINED		Significant[1] Differences	.028 (N=235)		Unable to Pool	.023[2] (N=215)

1. 11/25, 11/27, and 12/04 (test dates)
2. 11/18, 11/25, and 11/27 (test dates)

the .01 level (i.e., there were no significant differences between them at the .01 level); therefore, they were pooled into a combined value of 0.028 nmi and are so listed in the COMBINED row of table 1.

In the case of the merged targets, the Bartlett test showed significant differences between the four pooled standard deviations. The Bartlett test was then reapplied to the three highest merged standard deviations in table 1, and no significant difference at the .01 level was found. These were then combined into an overall pooled value of 0.023 nmi and are so shown in table 1. The three highest standard deviations were selected so as to give a more conservative overall value.

It will be noted from table 1 that the means for November 18, 1974, are substantially more positive-going than the corresponding means for the remaining 3 days. This was due to a bias introduced by the fact that a different wire-strap card was used in the ARTS III on the November 18th runs than was used during the other 3 days of the ARTS/EAIR flights. Since the means for November 18 were thus atypical, they were excluded from consideration in the computation of the combined means.

An analysis of variance test (appendix C4) was performed on the means for the remaining 3 days for the beacon-only targets. Significant differences were shown between these means; hence, they could not be pooled. In the case of the merged targets, only two of the four daily means were available for consideration, since the mean for November 18 was excluded due to the wire-strap card, while the mean for December 4 was excluded due to the fact that the standard deviation for that day was incompatible with those of the other three days. Therefore, pooling of the means for either target type was not attempted. Instead, cumulative relative frequency distribution curves of the range errors for the beacon-only and merged targets were prepared. These curves are shown in figures 13 and 14. Inbound and outbound bias was averaged out in these curves. The errors for November 18 were excluded from these frequency distributions, since this was an atypical day. As seen from figure 13, 99 percent of the 173 range errors for the beacon-only targets fell between -0.1175 nmi (-714 feet) and +0.0425 nmi (+258 feet), which is an interval of 975 feet. Correspondingly for the merged targets, figure 14 shows that 99 percent of the 219 range errors fell between -0.1315 nmi (-800 feet) and -0.018 nmi (-109 feet) which comprises an interval of 690 feet.

RANGE ACCURACY--STRAIGHT FLIGHT--ARTS/THEODOLITE. The statistical test procedures shown in appendices C2 and C3 were applied to the standard deviations of the various data groupings. The allowable consolidations resulted in an overall standard deviation of 0.025 nmi for the beacon-only targets and 0.029 nmi for the merged targets, based on sample sizes of 407 and 238, respectively. These are shown in table 2.

The statistical test procedure shown in appendix C4 (analysis of variance test) was used to determine if the means of the various data groupings could

be assumed to be from the same normal distribution. The test showed significant differences at the .01 level of significance; therefore, the means could not be combined. Table 2 also shows the corresponding data for the ARTS/EAIR flights for purposes of comparison.

As seen from table 2, the overall standard deviations vary from 0.023 to 0.029 nmi (140 to 176 feet). The difference (0.006 nmi) is but 36 feet.

TABLE 2. RANGE ERROR INTERVALS FOR STRAIGHT FLIGHT

Target Type	Range Interval (nmi)	Standard Deviation (Overall) (nmi)
Beacon-Only	3 to 10 (ARTS - THEO)	0.025 (N=407)
	10 to 40 (ARTS - EAIR)	0.028 (N=235)
Merged	3 to 10 (ARTS - THEO)	0.029 (N=238)
	10 to 40 (ARTS - EAIR)	0.023 (N=215)

Concerning the means, even with the bias due to the change in wire-strap cards accounted for, the remaining ARTS/EAIR means and all ARTS/Theodolite means were determined not to be from the same normal populations; hence, grand means could not be determined.

RANGE ACCURACY--TANGENTIAL VERSUS STRAIGHT FLIGHT. Table 3 shows a comparison of range errors occurring when the aircraft was in a tangential attitude versus when it was in straight flight. This comparison is given for both beacon-only and merged targets. This study was made on the December 4, 1974, flights of the ARTS/EAIR tests. The mean pairs were tested for uniformity by means of the Aspin-Welch test (appendix C5). It is seen in table 3 that the difference in the means of the straight and tangential portions of the flight for beacon-only targets was not significant at the .01 level, while in the case of the merged target means, the difference was not significant at the .05 level. Likewise, the differences in standard deviations between straight and tangential flights were not significant at the .05 level for both target types.

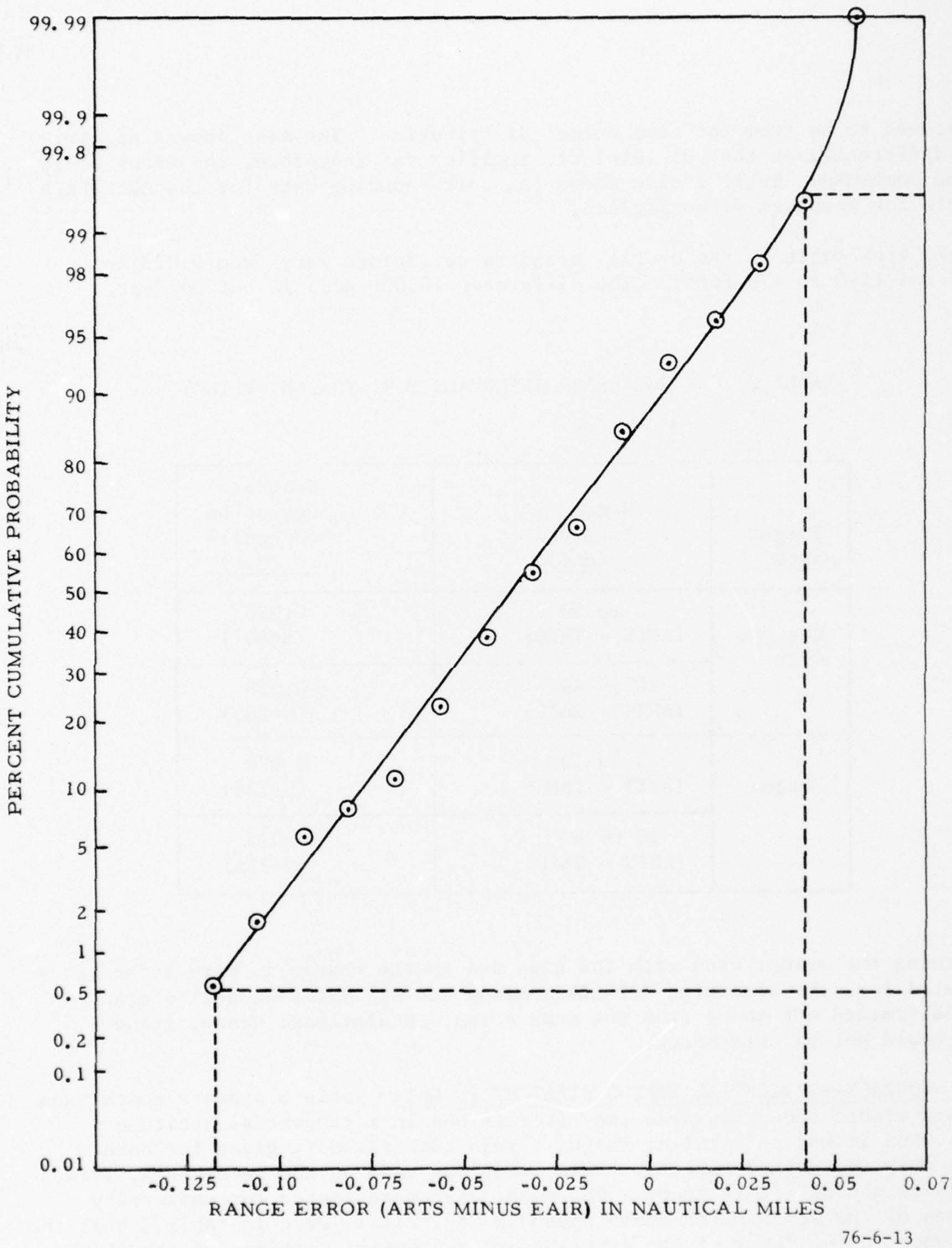

FIGURE 13. RELATIVE FREQUENCY DISTRIBUTION--ARTS III RBTL RANGE ERRORS, BTL ONLY

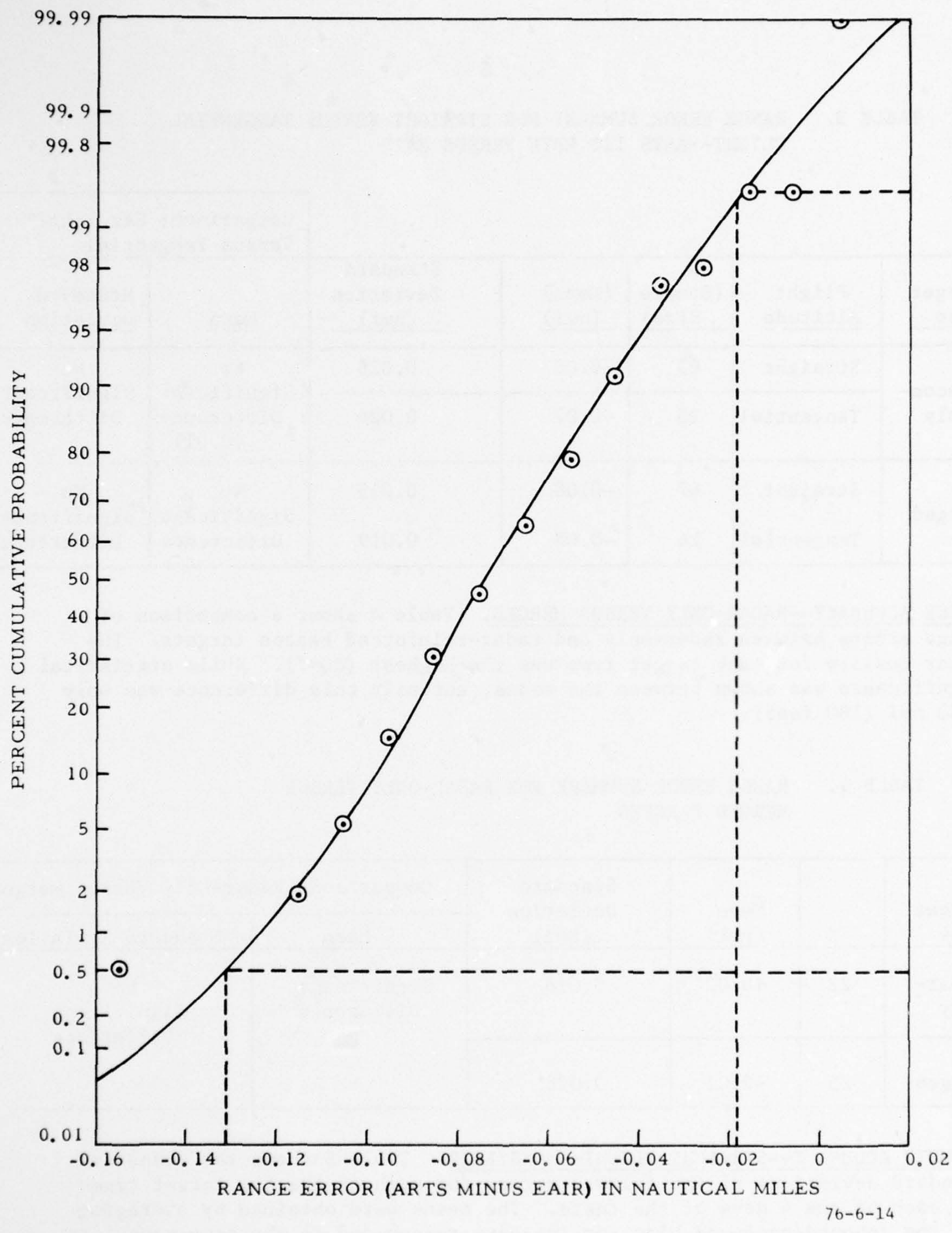

FIGURE 14. RELATIVE FREQUENCY DISTRIBUTION--ARTS III RBTL RANGE ERRORS

TABLE 3. RANGE ERROR SUMMARY FOR STRAIGHT VERSUS TANGENTIAL FLIGHT--ARTS III RBTL VERSUS EAIR

Target Type	Flight Altitude	N (Sample Size)	(Mean) (nmi)	Standard Deviation (nmi)	Comparison: Straight Versus Tangential	
					Mean	Standard Deviation
Beacon-Only	Straight	63	-0.05	0.029	No Significant Difference (0.01)	No Significant Difference
	Tangential	25	-0.07	0.024		
Merged	Straight	67	-0.08	0.015	No Significant Difference	No Significant Difference
	Tangential	16	-0.08	0.019		

RANGE ACCURACY--RADAR-ONLY VERSUS MERGED. Table 4 shows a comparison of range errors between radar-only and radar-reinforced beacon targets. The radar quality for each target type was the highest (RQ=7). While statistical significance was shown between the means, actually this difference was only 0.03 nmi (180 feet).

TABLE 4. RANGE ERROR SUMMARY FOR RADAR-ONLY VERSUS MERGED TARGETS

Target Type	N	Mean (nmi)	Standard Deviation (nmi)	Comparison: Radar-Only Versus Merged	
				Mean	Standard Deviation
Radar-Only	22	+0.02	0.018	Significant Difference	No Significant Difference
Merged	25	-0.01	0.028		

AZIMUTH ACCURACY--STRAIGHT FLIGHT--ARTS/EAIR. Table 5 shows the means and standard deviations of the azimuth errors for each of the two target types for each of the 4 days of the tests. The means were obtained by averaging out the inbound/outbound bias for the same reason and in the same manner as was done for the range errors. The daily standard deviations were likewise obtained by comparing inbound and outbound standard deviations for each target type by means of an F-test and combining them, since all eight pairs showed no significant differences.

TABLE 5. AZIMUTH ERROR SUMMARIES--ARTS III RBTL VERSUS EAIR DURING STRAIGHT FLIGHT

	Beacon-Only Targets			Merged Targets		
Test Date (1974)	N	Mean (degrees)	Standard Deviation (degrees)	N	Mean (degrees)	Standard Deviation (degrees)
11/18	62	1.04	0.211	63	0.94	0.176
11/25	61	1.00	0.142	64	0.91	0.135
11/27	49	1.21	0.201	63	1.03	0.165
12/04	63	1.01	0.141	67	0.90	0.129
Combined		Significant Difference	0.175 (N=235)		Significant Difference	0.152 (N=257)

The four pooled daily standard deviations for azimuth error for each target type were now tested for homogeneity by means of Bartlett's test, as was done in the case of the range errors. The values for the merged targets passed at the .01 level; however, the beacon-only standard deviations failed at the .01 level. However, due to a certain similarity pattern shown by the standard deviations of both target types, and, inasmuch as the four pooled daily standard deviations for the merged targets passed at the .01 level, it was decided to pool all 4 days of each target type. The pooled values are shown in the COMBINED row of table 5.

The four daily means for each target type were tested for uniformity by an analysis of variance test. The tests for both target types failed, indicating significant differences in the means; hence, the means could not be combined.

Cumulative relative frequency distribution curves of the azimuth errors for the beacon-only and merged target reports were prepared. These curves are shown in figures 15 and 16. Inbound and outbound bias was averaged out. As seen from figure 15, 99 percent of the azimuth errors for the beacon-only targets should fall between 0.61° and 1.54°, which is an interval of 0.93°. Correspondingly for the merged targets, figure 16 shows that 99 percent of the azimuth errors should fall between 0.58° and 1.34°, which comprises an interval of 0.76°.

AZIMUTH ACCURACY--STRAIGHT FLIGHT--ARTS/THEODOLITES. As in the case of the range errors, the F- and Bartlett's tests were applied to the standard deviations of the various azimuth data groupings. The allowable consolidations resulted in an overall standard deviation for azimuth errors of 0.250° for the beacon-only targets and 0.171° for the merged targets based on sample sizes of 345 and 186, respectively. These are shown in table 6.

TABLE 6. AZIMUTH ERROR INTERVALS FOR STRAIGHT FLIGHT

Target Type	Range Interval (nmi)	Standard Deviation (Overall) (Degrees)
Beacon-Only	3 to 10 (ARTS - THEO)	0.250 (N=345)
	10 to 40 (ARTS/EAIR)	0.175 (N=235)
Merged	3 to 10 (ARTS/THEO)	0.171 (N=186)
	10 to 40 (ARTS/EAIR)	0.152 (N=257)

The statistical test procedure shown in appendix C4 (analysis of variance test) was used to determine if the means of the various data groupings could be assumed to be from the same normal distribution. The test showed significant differences; therefore, the means could not be combined. Table 6 also shows the corresponding data for the ARTS/EAIR flights for purposes of comparison.

As seen from table 6, the overall standard deviations vary from 0.152° to 0.250°. The difference is less than 0.1°. For both ARTS/EAIR and ARTS/Theodolite data, the daily azimuth means were determined not to be from the same normal populations; hence, grand means could not be determined. Therefore, the tolerance interval about the mean error in which at least 99.9 percent of the azimuth errors can be expected to lie with a 90 percent degree of confidence is provided in place of the grand means.

AZIMUTH ACCURACY--TANGENTIAL VERSUS STRAIGHT FLIGHT. Table 7 shows a comparison of azimuth errors occurring when the aircraft was in a tangential attitude versus when it was in straight flight. This comparison was made for both beacon-only and merged targets. Table 7 shows that for each of the two target types there were no significant differences in either the means or the standard deviations between straight and tangential flight attitudes.

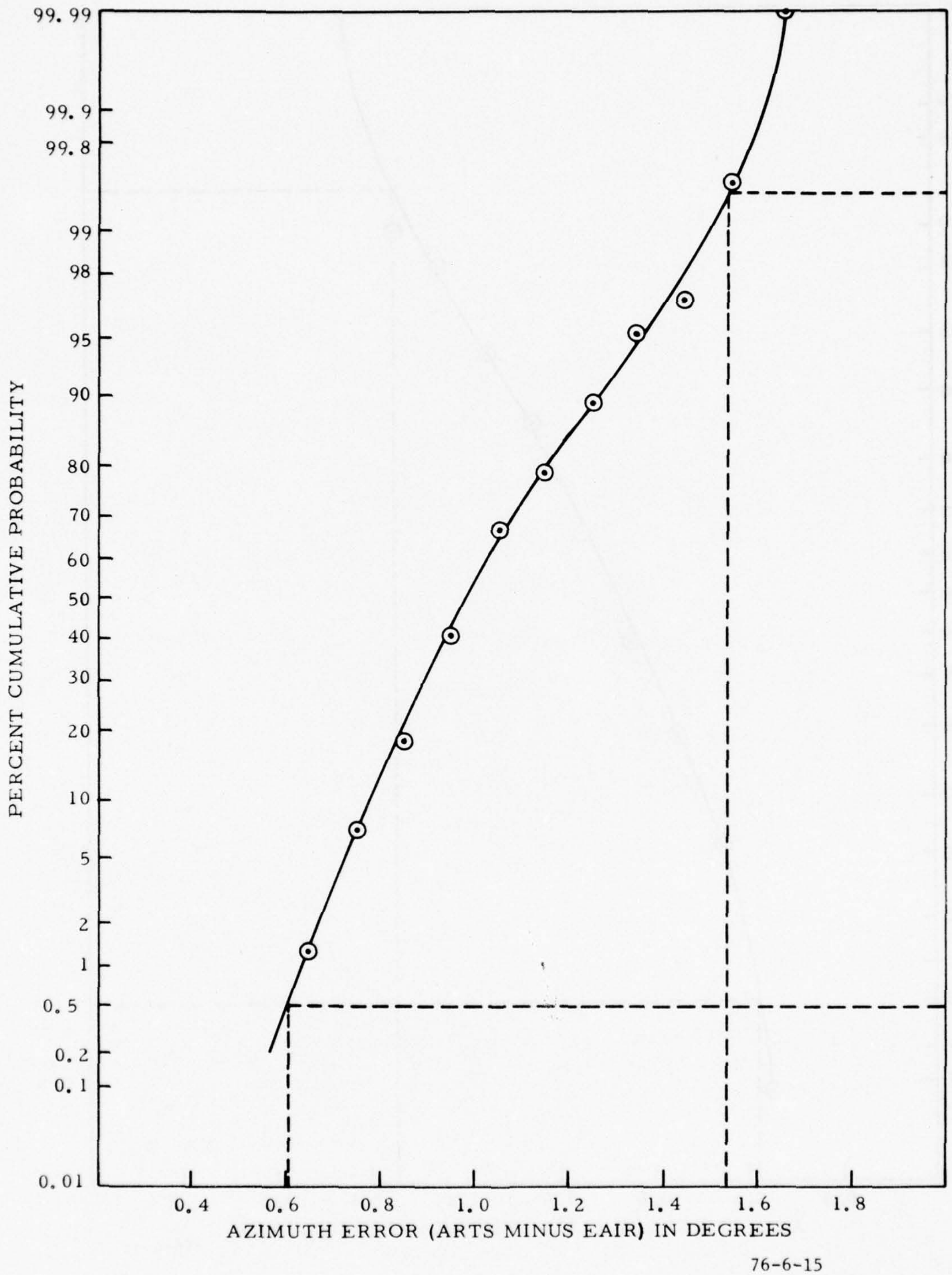

FIGURE 15. RELATIVE FREQUENCY DISTRIBUTION--ARTS III RBTL AZIMUTH ERRORS, BTL ONLY

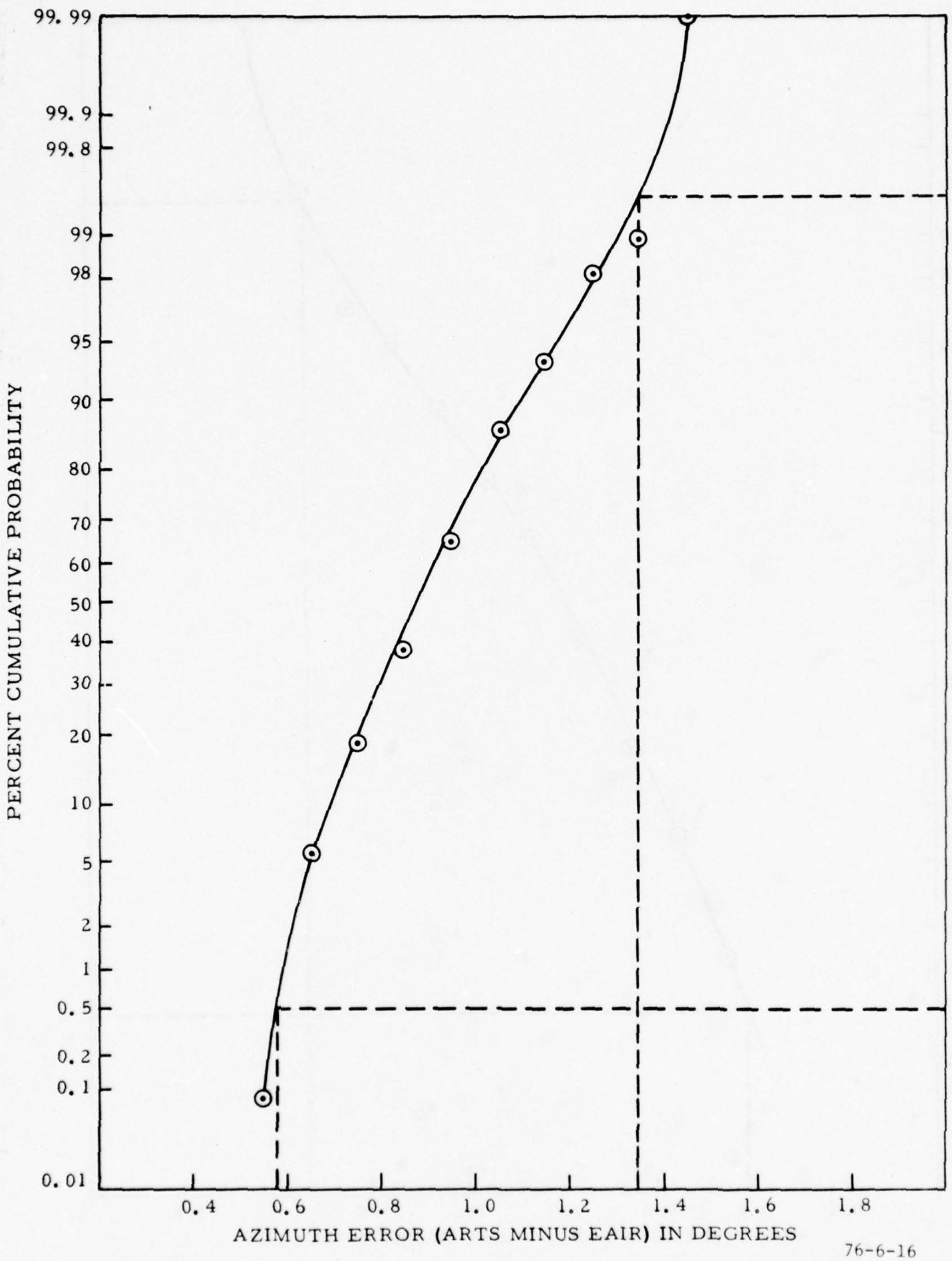

FIGURE 16. RELATIVE FREQUENCY DISTRIBUTION--ARTS III RBTL AZIMUTH ERRORS

TABLE 7. AZIMUTH ERROR SUMMARY FOR STRAIGHT VERSUS TANGENTIAL FLIGHT --ARTS/EAIR - December 4, 1974

Target Type	Flight Altitude	N (Sample Size)	(Mean) (degrees)	Standard Deviation (degrees)	Comparison: Straight Versus Tangential	
					Mean	Standard Deviation
Beacon-Only	Straight	63	1.01	0.142	No Significant Difference	No Significant Difference
	Tangential	25	0.98	0.147		
Merged	Straight	67	0.90	0.129	No Significant Difference	No Significant Difference
	Tangential	16	0.88	0.150		

TABLE 8. AZIMUTH ERROR SUMMARY FOR RADAR-ONLY VERSUS MERGED TARGETS

Target Type	N	Mean (degrees)	Standard Deviation (degrees)	Comparison: Radar-Only Versus Merged	
				Mean	Standard Deviation
Radar-Only	22	1.15	0.260	Significant Difference	No Significant Difference
Merged	22	0.92	0.234		

AZIMUTH ACCURACY--RADAR-ONLY VERSUS MERGED. Table 8 shows a comparison of azimuth errors between radar-only and radar-reinforced beacon targets. The radar quality for each target type was the highest (RQ=7). While statistical significance was shown between the means, actually this difference was less than 0.25°.

AIRCRAFT POSITION PREDICTING ACCURACY.

The means and standard deviations for the predicted position errors were compared to the corresponding values for the reported position errors in table 9 for the tangential flight situation. For the straight-flight situation, the inbound-outbound bias for the predicted position errors was averaged out, while corresponding standard deviations were tested for uniformity and then pooled, since there were no significant differences between them. These predicted position error values were compared with the corresponding reported position error values for both beacon-only and merged target reports in table 10.

It will be noticed from table 9 that for the tangential flight situation, there was a substantial difference in the corresponding means and standard deviations between the ARTS III predicted and reported errors in range. The standard deviation (variability about the mean) of the predicted range errors was 0.102 nmi (620 feet), while for the reported range errors, it was only 0.027 nmi. (165 feet). The mean predicted range error was -0.01 nmi (-50 feet), while for the reported position, the mean range error was -0.07 nmi (-425 feet); almost an order of magnitude greater. For the straight-flight situation, table 10 also shows that the standard deviation of the predicted range errors was still significantly greater than that of the reported range errors for both beacon-only and merged targets.

A possible explanation for the large difference in the predicted and reported mean range errors as observed in table 9 (tangential flight situation) is offered in figure 17. The aircraft was changing its course from an outbound to an inbound run. During part of this time, the aircraft was flying a counterclockwise arc with respect to the radar. The path of the ARTS III target reports, which occur every scan time, is shown by the solid arc of figure 17. Point C on this arc represents an ARTS III reported position at some particular radar scan time. The predicted position is mathematically projected by the tracking program from the history of several preceding reported positions. The predicted paths of the aircraft is shown by the dashed line in figure 17.

Let points A, B, and C represent the position of the aircraft as reported by the EAIR, as indicated by the ARTS III tracking program, and as reported by the ARTS III circuitry, respectively, for a given point in time. The distance of each of these three points from the radar site, O, can be represented by the line segments OA, OB, and OC, respectively.

TABLE 9. REPORTED VERSUS PREDICTED POSITION ERROR SUMMARIES--TANGENTIAL FLIGHT (ARTS/EAIR DATA OF December 4, 1974)

Error Category	ARTS III Reading	Mean (nmi)	Standard Deviation (nmi)	Comparison	
				Mean	Standard Deviation
Range	Reported Position	-0.07 nmi (N=25)	0.027 nmi (N=25)	Significant Difference	Significant Difference
	Predicted Position	-0.01 nmi (N=42)	0.102 nmi (N=42)		
Azimuth	Reported Position	0.93° (N=25)	0.231° (N=25)	No Significant Difference	No Significant Difference
	Predicted Position	0.83° (N=42)	0.267° (N=42)		

TABLE 10. REPORTED VERSUS PREDICTED POSITION ERROR SUMMARIES--STRAIGHT FLIGHT (ARTS/EAIR DATA OF December 4, 1974)

Error Category	ARTS III Position	Mean	Standard Deviation	Comparison	
				Mean	Standard Deviation
Range	Predicted	-0.09 nmi (N=62)	0.045 nmi (N=62)	Unable to Compare	Significant Difference
	Reported (Beacon-Only)	-0.05 nmi (N=63)	0.029 nmi (N=63)		
	Predicted	-0.09 nmi (N=62)	0.045 nmi (N=62)	Unable to Compare	Significant Difference
	Reported (Merged)	-0.08 nmi (N=67)	0.016 nmi (N=67)		
Azimuth	Predicted	0.88° (N=62)	0.136° (N=62)	Significant Difference	No Significant Difference
	Reported (Beacon-Only)	1.01° (N=63)	0.141° (N=63)		
	Predicted	0.88° (N=62)	0.136° (N=62)	No Significant Difference	No Significant Difference
	Reported (Merged)	0.90° (N=67)	0.129° (N=67)		

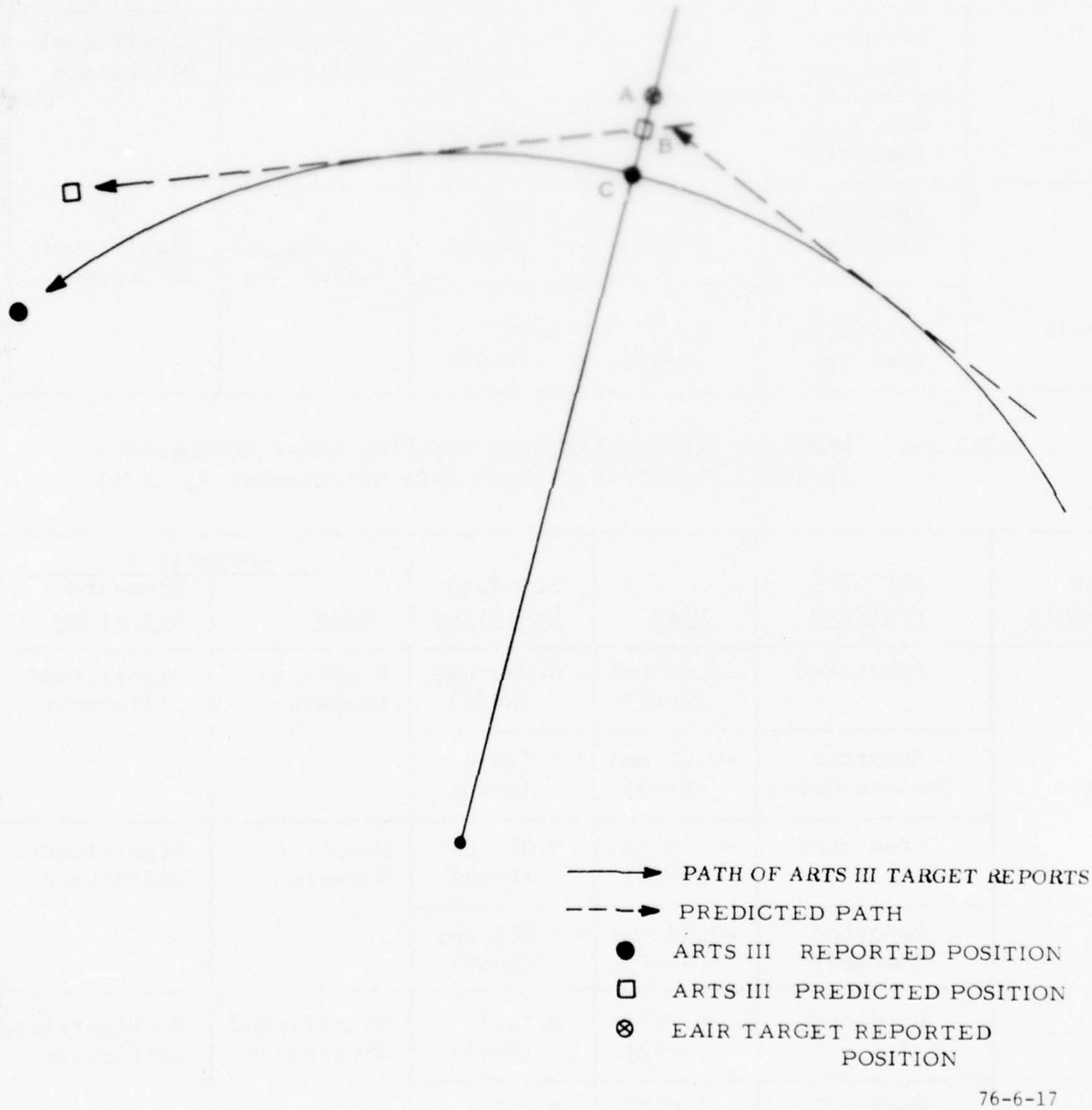

FIGURE 17. PREDICTED POSITION VS. REPORTED POSITION IN TURNING FLIGHT SITUATIONS

The position error is, by definition, ARTS minus EAIR. Then the predicted position error will be OB minus OA, or the line segment -BA. The corresponding reported position error will be OC minus OA, or line segment -CA. It will be seen that the reported error (-CA) is larger in magnitude (more negative) than the corresponding predicted error (-BA). This agrees with the observed means in range for the tangential flight situation shown in table 9, wherein the reported mean (-0.07 nmi) was larger (more negative) than the predicted mean (-0.01 nmi). In the case where the EAIR target reported position is inside the ARTS III reported position arc, i.e., ARTS III reports the aircraft position further in range than it actually is, the predicted mean would be greater than the reported mean.

The greater variability of the predicted error versus the reported error may be attributed to the fact that the reported target variability is due mainly to system noise; the predicted error variability is compounded by changes in firmness values which effect the position and velocity of the predicted target.

AIRCRAFT POSITION DISPLAYING ACCURACY.

Appendix D4 shows that the best estimate of range errors between 2 and 9 inches from the display center varies between -0.07 nmi at 2 inches and -0.17 nmi at 9 inches, with at least 95 percent of the individual range errors lying between 0.01 and -0.25 nmi. The best estimate of azimuth errors between 2 and 9 inches from the display center varies from -0.07 nmi (-1.6°) at 2 inches to 0.09 nmi (0.45°) at 9 inches, with at least 95 percent of the individual azimuth errors lying between -0.16 and +0.15 nmi. The standard deviations of the errors from each quadrant were pooled to provide overall estimates of range and azimuth error standard deviation (N=40). The range and azimuth error standard deviation estimates were 0.03 nmi and 0.265°, respectively.

AIRCRAFT SEPARATION REPORTING ACCURACY.

Standard deviations for the fixed and variable separation ASMS flights as well as for the Theodolite flights are summarized in table 11. Standard deviations were computed for the approaching and receding portion of each variable separation (overtake or angular convergence) flight. The resulting standard deviations were tested by means of the Bartlett's test. No significant differences between them were found; therefore, they were pooled into a value of 0.051 nmi and are so shown in table 11.

The standard deviations obtained for the fixed ASMS flights (0.042 nmi) and the variable separation ASMS flights (0.051 nmi) were compared by the F-test. No significant difference was found; therefore, they were combined into an overall value of 0.047 nmi based on a sample size of 324 separation measurements.

TABLE 11. SEPARATION ERROR SUMMARY

	Fixed Separations		Variable Separations		Overall	
Measurement System	Sample Size	S.D.* (nmi)	Sample Size	S.D.* (nmi)	Sample Size	S.D.* (nmi)
ASMS	146	0.042	178	0.051	324	0.047
THEODOLITES	-	-	574	0.047	574	0.047

* Standard Deviation

AIRCRAFT RESOLUTION ABILITY.

The resolution percentages are shown in table 12 for range separation and in table 13 for azimuth separation and are shown graphically in figures 18a and 18b for range and azimuth separations, respectively. As seen in figure 18a, the ARTS III will successfully resolve 95 percent of aircraft separated in range (longitudinally) by 2.5 nmi or more. At a range separation of 2.0 nmi or more, 90 percent of such aircraft will be successfully resolved. Figure 18b shows that more than 90 percent of aircraft separated in azimuth by 6° or more will be successfully resolved. Resolution of beacon targets which overlay in range or azimuth is addressed under Simulation Results, page 51.

MODE C ALTITUDE REPORTING ACCURACY.

The standard deviations of the altitude errors from each of the four quadrants were tested by Bartlett's test (appendix C3). No significant differences were found; therefore, they were consolidated into an overall standard deviation of 27.44 feet. This was based upon 214 measurements.

The means of the altitude errors are clustered about 1 foot for all except one quadrant (210°) for which the mean was 28.44 feet. An analysis of variance test (appendix C4) showed significant differences between the 210° mean and the means from the other three quadrants. There were no significant differences between the other three means; therefore, they were combined into an overall mean of 1.06 feet.

PREDICTED GROUNDSPEED ACCURACY.

The groundspeed errors obtained from the November 8 ARTS/Theodolite flights were observed to have a mean of 4.6 knots and a standard deviation of 7.5 knots. This was based upon a sample size of 22 1-minute intervals.

OVERALL POSITION REPORTING AND DISPLAYING ACCURACY.

Based on the highest standard deviation estimates of 0.029 nmi for position reporting range errors and 0.030 nmi for radar display range errors, the overall value of standard deviation for reporting and displaying range error accuracy was $\sqrt{0.029^2 + 0.030^2}$, or 0.042 nmi. In a similar manner, using the highest standard deviation estimate of 0.250° for position reporting azimuth errors and 0.265° for radar display azimuth errors, the overall value of standard deviation for reporting and displaying azimuth error accuracy was 0.364°.

SUMMARY OF RESULTS.

The results of the live testing are summarized below in terms of the five project objectives.

TABLE 12. TARGET RESOLUTION PROBABILITY VERSUS RANGE SEPARATION

Range Separation In Nautical Miles	Total Number of Radar Scans Observed	Number of Scans For Which both Aircraft Were Reported	Percentage Resolution
0 to 0.49	30	11	37
0.50 to 0.99	32	15	47
1.00 to 1.49	32	26	81
1.50 to 1.99	31	26	84
2.00 to 2.49	26	24	93
2.50 to 2.99	24	23	96
3.00 to 3.49	15	15	100

These data were collected at ranges varying from approximately 3 to 20 nmi from the ASR-5 with an ATCBI-3 interrogator beamwidth of 4.5°. Percent resolution values are directly related to the presence or absence of both targets within the ATCBI beamwidth.

TABLE 13. TARGET RESOLUTION PROBABILITY VERSUS AZIMUTH SEPARATION

Azimuth Separation in Degrees	Total Number of Radar Scans Observed	Number of Scans For Which Both Aircraft Were Reported	Percentage Resolution
0 to 0.99	46	31	67
1.00 to 1.99	27	11	41
2.00 to 2.99	65	26	40
3.00 to 3.99	48	38	79
4.00 to 4.99	17	12	71
5.00 to 5.99	19	10	53
6.00 to 6.99	14	13	93
7.00 to 7.99	27	25	93
8.00 to 8.99	18	16	89
9.00 to 9.99	14	13	93

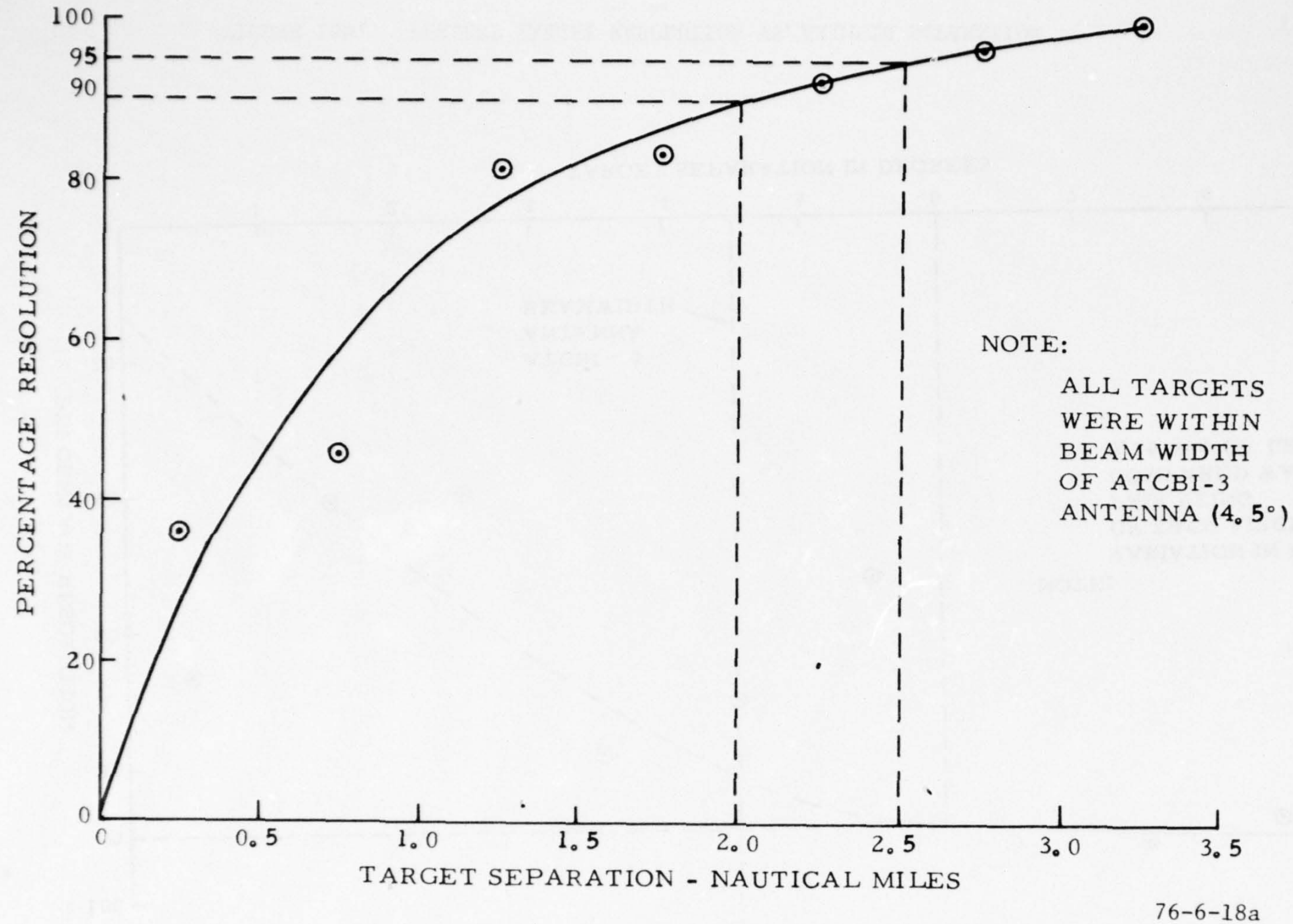

FIGURE 18a. PERCENT TARGET RESOLUTION VS. RANGE SEPARATION

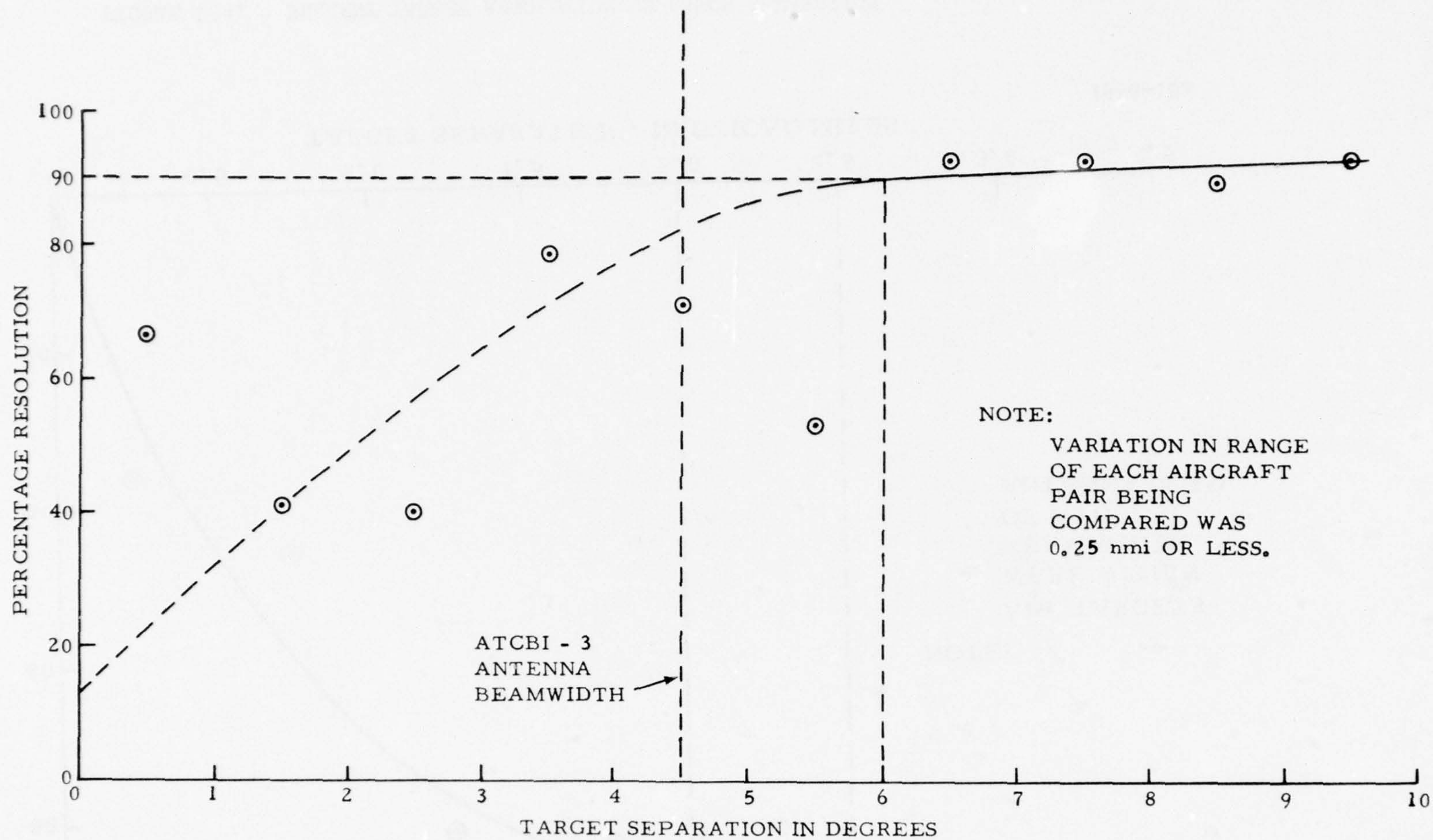

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FIGURE 18b. PERCENT TARGET RESOLUTION VS. AZIMUTH SEPARATION

AIRCRAFT POSITION REPORTING ACCURACY. For straight-line flights, between 3 and 40 nmi from the ASR-5, the standard deviations of the range errors varied between 0.023 and 0.029 nmi (140 and 176 feet), while the standard deviations of the azimuth errors varied between 0.152° and 0.250°. This included both beacon-only and merged (radar-reinforced beacon) targets. Sample sizes varied from 186 to 407 target reports.

Due to various physical biases which manifested themselves, it was statistically impossible to obtain a grand overall mean of range or azimuth errors. However, based upon data from 3 days of ARTS/EAIR flights (10 to 40 nmi), 99 percent of the range errors for the beacon-only targets occurred between -0.12 and +0.04 nmi, while for the merged targets, they occurred between -0.13 and -0.02 nmi. Using all 4 days of ARTS/EAIR flights, 99 percent of the azimuth errors for the beacon-only targets fell between 0.60° and 1.5°, while for the merged targets, they occurred between 0.6° and 1.35°.

The results for the tangential portions of the flights did not differ significantly from those of the straight portions.

The standard deviations for radar-only target errors did not differ significantly from those of the merged targets. Statistically, the means for both range and azimuth errors of the radar-only targets significantly differed from those of the merged targets. Actually, however, this difference was 0.03 nmi (180 feet) for the range error means and 0.23° for the azimuth error means. The radar-only means were the larger (more positive.)

Based on the highest standard deviation estimates of 0.029 nmi and 0.250° for range and azimuth errors, respectively, there is a 90-percent degree of confidence that at least 99.9 percent of the target position reporting errors will be within ±0.10 nmi of the mean error in range and ±0.87° of the mean error in azimuth.

AIRCRAFT POSITION PREDICTING ACCURACY. It was found that the standard deviation of the range errors for PREDICTED position errors was significantly larger than that for the REPORTED position errors. This was especially true for the tangential flight situation, where the standard deviation of the range error for the PREDICTED position was 0.102 nmi, while for the REPORTED position, it was only 0.027 nmi. The magnitude of the mean reported range error was much greater than that of the mean predicted range error (-0.07 nmi versus -0.01 nmi).

Based on the standard deviation estimates of 0.102 nmi in range and 0.267° in azimuth, respectively, for tangential flight, there is a 90-percent degree of confidence that at least 99.9 percent of the target position prediction errors will fall within ±0.40 nmi of the mean error in range and ±1.04° of the mean error in azimuth.

Based on the corresponding standard deviation estimates of 0.045 nmi and 0.136°, respectively, for straight flight, the corresponding tolerance limits are ±0.17 nmi and ±0.51°, respectively.

AIRCRAFT POSITION DISPLAYING ACCURACY. Range and azimuth errors were correlated with the distance of the symbol from the display center. Between 2 and 9 inches from the display center, range error varied between -0.07 and -0.17 nmi, and azimuth error varied from -0.07 to +0.09 nmi for a 14-nmi range setting. At least 95 percent of the individual range errors should lie between +0.01 and -0.25 nmi, while at least 95 percent of the individual azimuth errors should lie between -0.16 and +0.15 nmi. The display range errors showed a mean of -0.12 nmi, with a standard deviation of 0.03 nmi. The display azimuth errors showed a mean of 0.13°, with a standard deviation of 0.265°.

Based on standard deviation estimates of 0.03 nmi in range and 0.265° in azimuth, there is a 90-percent degree of confidence that at least 99.9 percent of the radar display errors will fall within ±0.12 nmi of the mean range error and ±1.04° of the mean azimuth error. A more complete discussion of display error is presented in appendix D4.

AIRCRAFT SEPARATION REPORTING ACCURACY. The ARTS/ASMS separation errors for both fixed and variable aircraft separations were found to have a combined standard deviation of 0.047 nmi. Based on this estimate of standard deviation, there is a 90-percent degree of confidence that at least 99.9 percent of the target report separation errors will fall within ±0.163 nmi of the mean error.

AIRCRAFT RESOLUTION ABILITY. As shown by the resolution investigations, the ARTS III should successfully resolve 90 percent of aircraft separated in range (longitudinally) by 2.00 nmi or more and separated in azimuth (laterally) by 6° or more.

MODE C ALTITUDE REPORTING ACCURACY. The overall standard deviation for altitude errors (ARTS III mode C versus Theodolite) was 27.44 feet. The corresponding overall mean was 1.06 feet.

Based on the standard deviation estimate of 27.44 feet, there is a 90-percent degree of confidence that at least 99.9 percent of the mode C altitude report errors will be within ±96 feet of the mean error.

DISPLAYED GROUNDSPEED ACCURACY. Average ARTS versus Theodolite groundspeed error was 4.6 knots, with a standard deviation of 7.5 knots.

Based on the standard deviation estimate of 7.5 knots, there is a 90-percent degree of confidence that at least 99.9 percent of the groundspeed prediction errors will be within ±32 knots of the mean error.

OVERALL ARTS III POSITION REPORTING AND DISPLAYING ACCURACY. Based on the standard deviation estimates of 0.042 nmi for range errors and 0.364° for azimuth errors, there is a 90-percent degree of confidence that at least 99.9 percent of the target position reporting and displaying errors will fall within ±0.16 nmi of the mean range error and ±1.43° of the mean azimuth error.

DATA METHODOLOGY (SIMULATION FLIGHT TESTS)

EDITING.

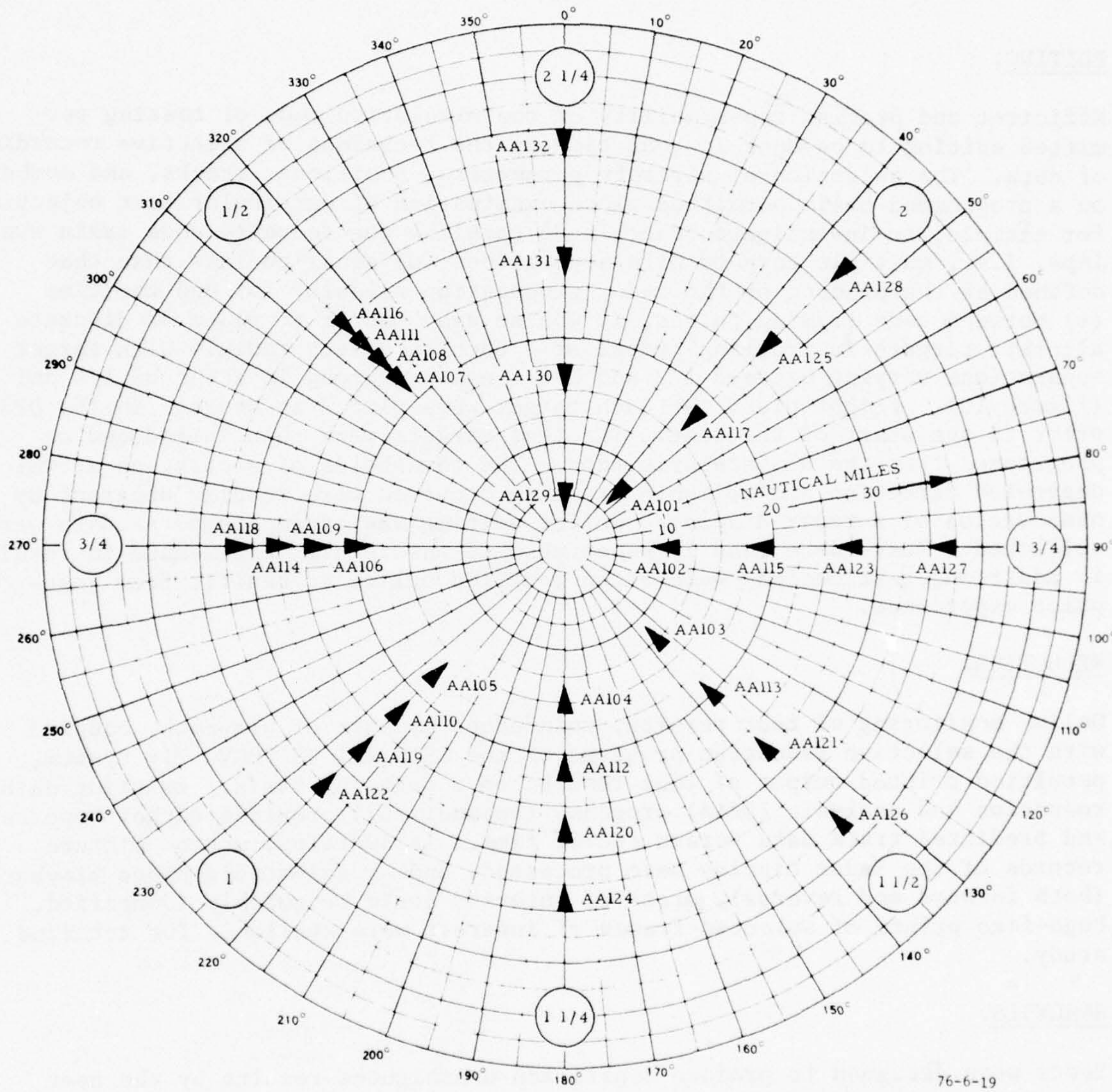
Efficient and precise repeatability of the simulation mode of testing permitted editing to be done in real time by the technique of selective recording of data. The selection of aircraft parameters, positions, tracks, and numbers on a programmed basis permitted close examination of particular test objectives. For example, to investigate beacon code garbling due to reply code train overlaps, i.e., multiple targets with separations (d) equal to less than that defined by the product of the radar propogation velocity (v) and the time (t) between code framing pulses, it was an easy matter to place 32 discrete aircraft targets in trailing groups of 4 each on select radials with target separations varying between 1/2 and 2 3/4 nmi per group in steps of 1/4 nmi (figure 19). Flight plans for each target were placed in storage in the DPS prior to the start of the test. The test targets were then introduced as programmed from the RBS scenario tape. The thresholds of separation at which ungarbled detection and reliable tracking occurred were readily apparent by observation of a radar display. Online editing was accomplished as data were collected. Tests were readily repeatable to ensure high confidence in results; in addition, test designs were often modified online to benefit from just-prior experience.

REDUCTION.

Online monitoring of test results, reinforced by ease of playback, coupled with the selective reduction programs of the ARTS III UNISERVO VIc System, permitted printed output of test results on a next-day basis. Existing data reduction and analysis (DR&A) programs (appendix B1) provided target reports and predicted track data versus sector time. In addition, motion picture records of the Radar Display were processed, and by selectable-speed playback (both forward and reverse), areas of interest could be quickly identified. Page-size prints of selected frames of interest were available for detailed study.

ANALYSIS.

Tests were designed to produce finite and unambiguous results by the near absolute control of variables. The analysis was achieved by real time monitoring of ARTS responses to specific target parameters. Hard copy verification was achieved by use of the ARTS III 9300 Processor System and by radar display photos. Simulation focused attention on specified situations in a manner wherein results become almost obvious.



SCENARIO 000: 32 TARGETS, 4 ON EACH 45° OF AZIMUTH, VARIOUS TRAIL SEPARATIONS FROM 1/2 TO 2 1/4 NMI, DISCRETE BEACON AND RADAR (MTI), INBOUND FROM 40 NMI.

SCENARIO 001: AS 000, EXCEPT RADAR ONLY.

FIGURE 19. RBS SCENARIO 000-MINIMUM RANGE SEPARATION EVALUATION

RESULTS (SIMULATION FLIGHT TESTS)

GARBLING, TRAIL SEPARATION.

Figure 19 depicts RBS scenarios 000 and 001 during which multiple target trail separations varying from 1/2 to 2 1/4 nmi were maintained on cardinal radials (every 045°). As noted in radar display photograph (figure 20), scenario 000, which shows all beacon targets with stored flight plans, garbling voided all attempts to establish tracking until a separation of 1 3/4 nmi was reached. Again, however, at 2 nmi, mode C garbling and false idents regularly occurred. This is further documented in figure 21, UNISERVO VIc printout, which shows the "report" and "track" garble condition at the 2-nmi separation. Figure 22, UNISERVO VIc printout, is included to contrast radar-only detection and tracking now successfully occurring at the 1/2-nmi separation level.

GARBLING, AZIMUTH SEPARATION.

Figure 23 depicts RBS scenarios 003 and 004 during which multiple target trail separations again were varied between 1/2 and at least 2 1/4 nmi. This test, however, involved targets flown abeam to the ASR, so that the separation would appear in the azimuth sense. Again, as noted on radar display photograph (figure 24) and UNISERVO VIc printout (figure 25), garbling voided tracking until a separation of 1 3/4 nmi was achieved, followed again by mode C garbling and false idents at the 2-nmi limit. Figure 26, RBS scenario 008 depicting beacon targets separated by slightly greater than one beamwidth (5°), reveals that when garbling no longer occurred, all targets were successfully detected as shown by the UNISERVO VIc printout (figure 27). Target reports on successive sweeps effectively define an azimuth dimension of one ATCBI beamwidth for each beacon target. Radar display photo (figure 28) again reveals that radar-only targets possess this limitation to a much lesser degree (0.5 nmi), due to the narrower ASR beamwidth and target reply duration.

TRACK SWAPPING.

Discrete beacon codes lose their fidelity if garbling occurs and the potential of track swaps arises. Figure 29 depicts RBS scenario 024. Targets in flights of two or three aircraft (first when discrete beacon was used and then radar-only) were flown on converging courses designed to cross over at a point 20 nmi from the ASR on the 270° radial. Figure 30, radar display photograph, shows that after convergence and separation, track AA101 has swapped with AA102, track AA103 has swapped with AA104, and BB104 has swapped with BB105. AA targets are discrete beacon radar-reinforced; BB targets are radar-only. Figure 31, UNISERVO VIc printout, shows these swaps, i.e., reported and assigned beacon codes uncorrelated, target identifications interchanged, mode C altitudes falsely correlated, etc.

Since these data were taken, the program has been reported corrected, which resulted in the elimination of discrete beacon target swaps and a marked improvement for radar-only and nondiscrete beacon targets. The results of

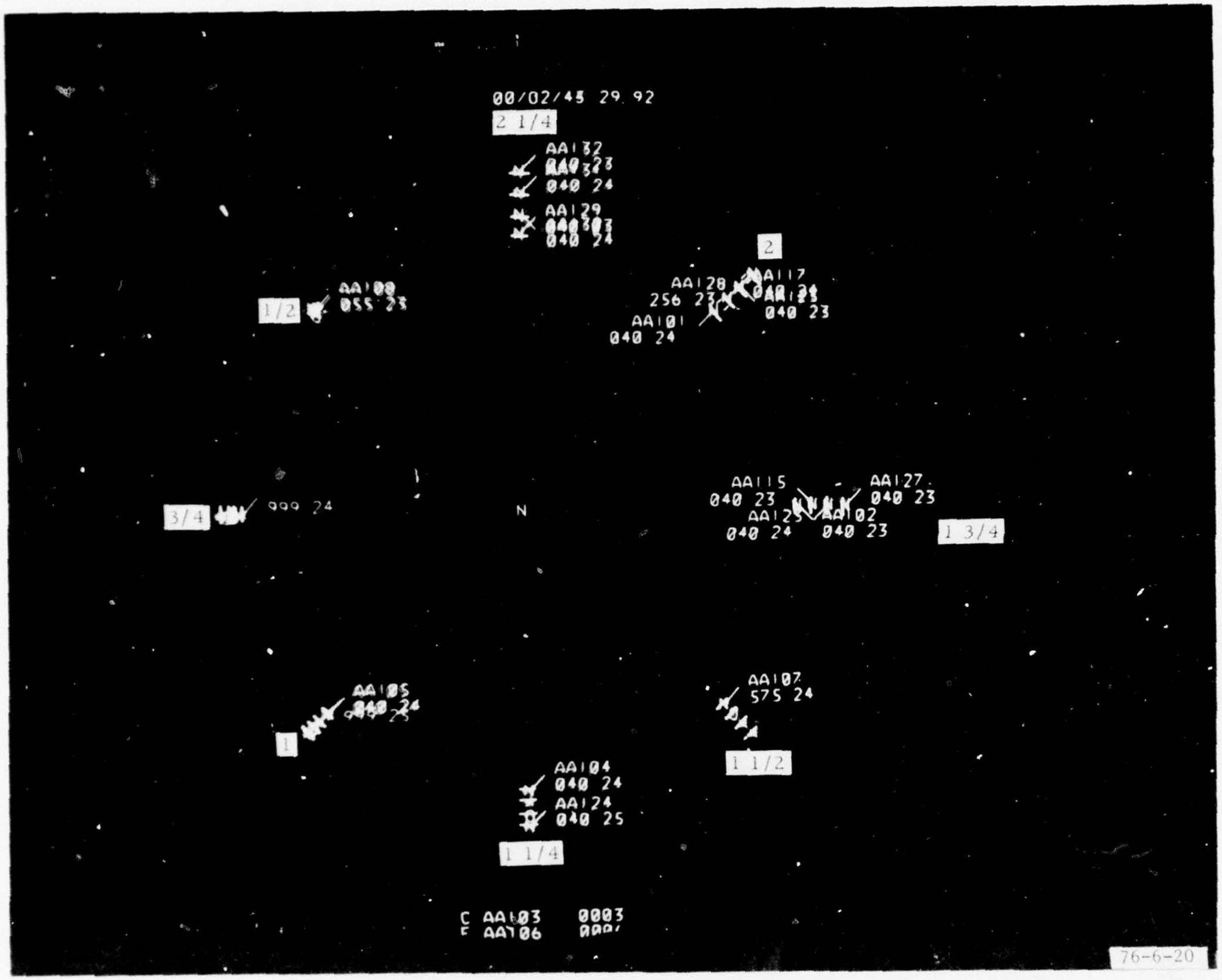


FIGURE 20. RADAR DISPLAY PHOTO--RBS SCENARIO 000, VARIOUS RANGE SEPARATIONS SHOWING EFFECTS OF GARBLING WITHIN 2 1/4 NMI

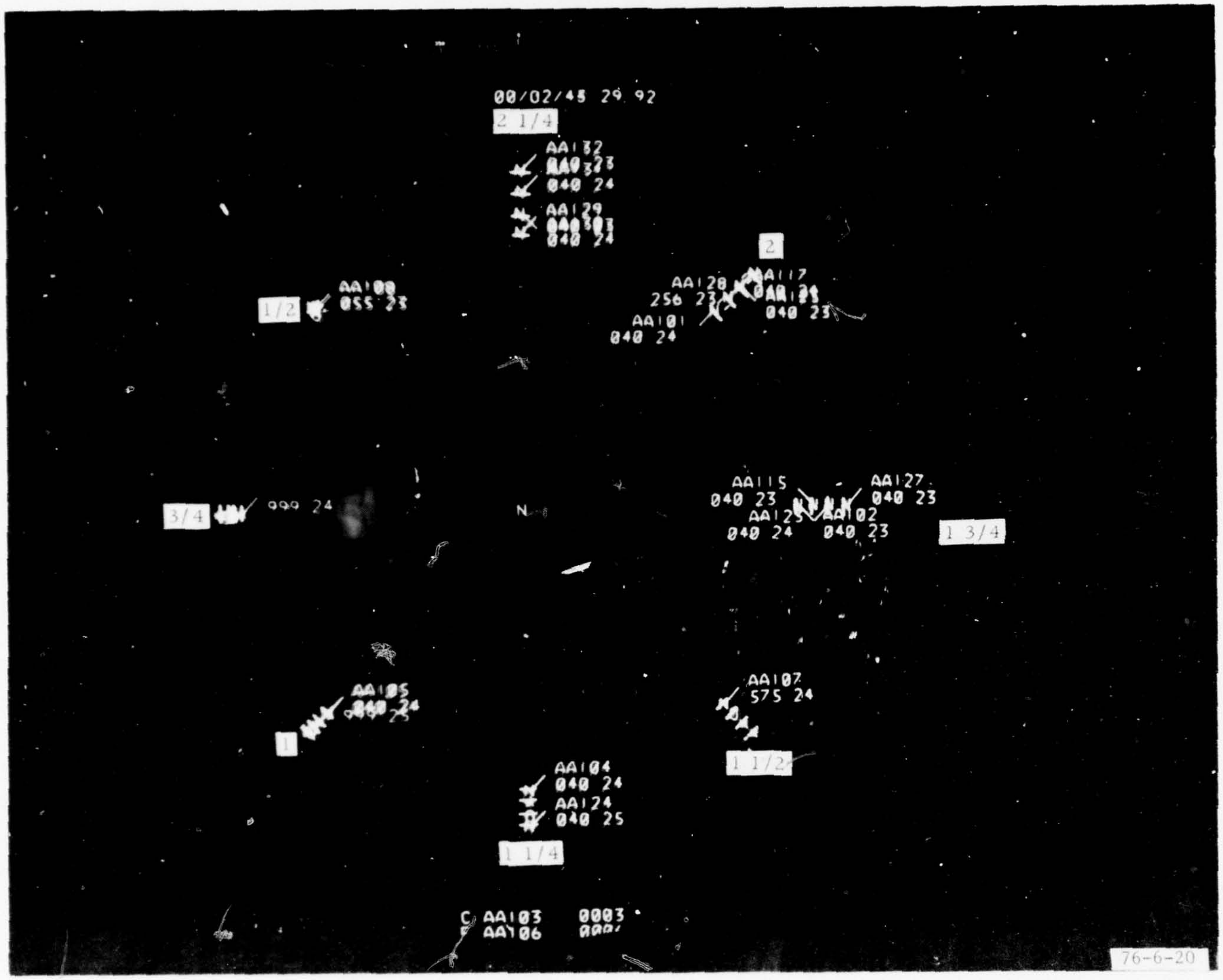


FIGURE 20. RADAR DISPLAY PHOTO--RBS SCENARIO 000, VARIOUS RANGE SEPARATIONS SHOWING EFFECTS OF GARBLING WITHIN 2 1/4 NMI

```
00:04:13.882 1SECTOR TIME
00:04:14.062 1SECTOR TIME
             1TARGET RPT          0000S  24.75 0035-3 040-3 7 0000S  26.75 0036-3 040-3 5 00015  29.06 0037-3 040-3 7
                                  0000S  31.06 0040-3 040-3 7 4086   26.81 RADAR        1 4089   29.13 RADAR        3
00:04:14.164 1SECTOR TIME
00:04:14.320 1SECTOR TIME
00:04:14.460 1SECTOR TIME
00:04:14.644  AA131   N 040 0037 0037 0000 29.00  00.01  29.01 F47 VEL 23 28.63 29.31 4082 0014 28.31 29.63 4068 0028
              0000020007 0000135000 1640300003 6770000100 0000010443 0004700000 0003714000 0010010000 3003730100
              4232300036 7377776059 0000000000 0204000000
00:04:14.646   AA129 N 040 0035 0035 0000 24.75  00.01  24.72 F47 VEL 22 24.38 25.06 4081 0015 24.06 25.36 4066 0030
              0000020007 0000130600 1427000003 7000000100 0000010443 0004700000 0003514000 0010010000 3003530100
              4232400050 7777776037 0000000000 0300000000
00:04:14.648  AA132   N 040 0040 0040 0000 31.06  00.01  31.07 F47 VEL 22 30.69 31.38 4082 0013 30.38 31.59 4069 0027
              0000020007 0000137040 1742300003 7010000000 0000010443 0004700000 0004014000 0010010000 3004030100
              4232500040 7777776035 0000000000 0150000000
00:04:14.650  AA130   N 040 0036 0036 0000 26.75  00.00  26.75 F47 VEL 22 26.36 27.06 4081 0014 26.06 27.38 4067 0029
              0000020007 0000132600 1527700000 7010077600 0000010443 0004700000 0003614000 0010010000 3003630100
              4232600035 7377776046 0000000000 0244000000
00:04:14.640 1SECTOR TIME
             1TARGET RPT          0509S  24.56 0001-3 040-3 7 0511ST 26.56 0021-1 040-3 7 0511ST 28.56 0031-3 040-3 7
                                  0516W  30.56 0034-3 000-0 7
00:04:14.757 1SECTOR TIME
00:04:14.898 1SECTOR TIME
00:04:15.072  AA128   N       0034 0034 0511 30.50  21.62  21.60 F47 VEL 22 30.19 30.88 0497 0524 29.88 31.19 0484 0538
              0000020007 0377536440 1263212636 7240072300 0000011562 0004700000 0003414000 0010010000 3003440000
              4233100046 7777776034 0000000000 0160000000
00:04:15.074   AA101 N 040 0001 0001 0511 24.50  17.31  17.35 F47 VEL 23 24.13 24.81 0496 0526 23.81 25.13 0481 0541
              0000020007 0377530400 1053110517 7220072300 0000011275 0004700000 0000114000 0010010000 1000130100
              4232700015 7777777777 0000000000 0244000000
00:04:15.074  AA125   N 040 0031 0031 0511 28.56  20.15  20.21 F47 VEL 22 28.19 28.86 0497 0525 27.88 29.19 0483 0539
              0000020007 0377534440 1206612046 7230072300 0000011275 0004700000 0003114000 0010010000 3003130100
              4233000033 7737776065 0000000000 0214000000
00:04:15.039 1SECTOR TIME
00:04:15.226 1SECTOR TIME
             1TARGET RPT          1020S  24.44 0002-3 040-3 4 1018S  26.19 0177-3 256-3 7 1018S  27.88 0027-3 040-3 7
                                  1020S  29.83 0173-3 000-0 7 1012   24.50 RADAR        4
00:04:15.357   AA117 N 040 0021 0021 0512 26.50  13.78  18.71 F47 VEL 23 26.13 26.81 0497 0526 25.81 27.13 0483 0541
              0000020007 0400132400 1126711307 7170072700 0000011562 0004700000 0002114000 0010010000 3002130100
              4233200055 7777776053 0000000000 0240000000
00:04:15.335 1SECTOR TIME
00:04:15.492 1SECTOR TIME
00:04:15.642  AA123   N 040 0027 0027 1016 27.88  27.89  00.34 F47 VEL 23 27.50 28.19 1002 1030 27.19 28.50 0988 1044
              0000020007 0774133700 0012615743 0060067700 0000012413 0004700000 0002714000 0010010000 3002730100
              4233320065 7777776063 0000000000 0224000000
00:04:15.646  AA102   N 040 0002 0002 1016 24.44  24.44  00.30 F47 VEL 22 24.06 24.75 1001 1031 23.75 25.06 0986 1046
              0000020007 0774130340 0011614161 0020070000 0000012413 0004700000 0000214000 0010010000 3000230100
              4233620014 7753776016 0000000000 0260000000
00:04:15.632 1SECTOR TIME
00:04:15.820 1SECTOR TIME
             1TARGET RPT          1529S  24.69 0003-3 040-3 7 1533S  26.13 0175-3 256-3 3 1529S  27.56 0025-3 040-3 7
                                  1532S  29.06 0172-3 000-0 7
00:04:15.929 1SECTOR TIME
00:04:16.062 1SECTOR TIME
00:04:16.357   AA107 N 040 0007 0003 1529 24.69  17.61 -17.27 F47 VEL 23 24.31 25.00 1514 1544 24.00 25.31 1499 1559
              0000020007 1374530540 6727110631 0600072400 0000013554 0004700000 0000714000 0010010000 3000330100
              4234120006 7777776010 0000000000 0260000000
00:04:16.359   AA121 N 040 0025 0025 1531 27.56  13.61 -19.36 F47 VEL 23 27.19 27.88 1516 1545 26.88 28.19 1502 1559
              0000020007 1375533440 6624411033 0600072400 0000013554 0004700000 0002514000 0010010000 3002530100
              4234200063 7777776050 0000000000 0230000000
00:04:16.226 1SECTOR TIME
00:04:16.406 1SECTOR TIME                                                                                     76-6-21
```

FIGURE 21. UNISERVO VIc PRINTOUT SHOWING GARBLING, RBS SCENARIO 000

```
00:05:32.281  AA119   N     0000 0000 2560 22.19 -15.72 -15.66 F47 VEL 23 21.81 22.50 2544 2575 21.50 22.81 2528 2591
              0000020007 2400126140 7012670107 0600405400 0000535273 0004710000 4000014000 0000000000 4000040000
              4246000064 7774000047 0000000000 0120000000
00:05:32.283  TRIAL TRK 0 0000 2034 22.81  00.48 -22.81 F12 VEL 23 22.44 23.13 2017 2051 00.00 00.00 0000 0000
              0000020000 1771026640 6446000173 0770002500 0000545451 0001200064 0000000403 0000000000 4000040000
00:05:32.164 1SECTOR TIME
             1TARGET RPT          3074   20.44 RADAR        7 3069   21.31 RADAR        7 3073   22.19 RADAR        7
                                  3069   22.81 RADAR        7
00:05:32.289 1SECTOR TIME
00:05:32.421 1SECTOR TIME
00:05:32.707  AA118   N     0000 0000 3070 22.75 -22.75 -00.05 F47 VEL 24 22.38 23.06 3054 3085 22.06 23.38 3039 3101
              0000020007 2777126600 7776364476 0040010300 0000536414 0004710000 4000014000 0000000000 4000040000
              4446500057 0004000046 0000000000 0004000000
00:05:32.703  AA114   N     0000 0000 3070 22.19 -22.20 -00.08 F47 VEL 22 21.81 22.50 3054 3085 21.50 22.81 3038 3101
              0000020007 2777126140 7775264713 0000410000 0000536145 0004710000 4000014000 0000000000 4000040000
              4446125067 7774000051 0000000000 0110000000
00:05:32.703  AA108   N     0000 0000 3071 20.44 -20.45 -00.03 F47 VEL 23 20.06 20.75 3054 3087 19.75 21.06 3038 3104
              0000020007 2777524340 7776765614 0030410000 0000536145 0004710000 4000014000 0000000000 4000040000
              4246300065 7774000023 0000000000 0300000000
00:05:32.715  AA109   N     0000 0000 3066 21.31 -21.30 -00.13 F47 VEL 23 20.94 21.63 3052 3084 20.63 21.94 3036 3100
              0000022007 2776125240 7773665253 7760410100 0000536145 1004710000 4000012000 0000000000 4000040000
              4246400005 7764000050 0000000000 0200000000
00:05:32.535 1SECTOR TIME
00:05:32.742 1SECTOR TIME
             1TARGET RPT          3586   20.63 RADAR        7 3587   20.94 RADAR        7 3586   21.50 RADAR        7
                                  3585   22.13 RADAR        7
00:05:32.853 1SECTOR TIME
00:05:33.015 1SECTOR TIME
00:05:33.156 1SECTOR TIME
00:05:33.419  AA111   N     0000 0000 3566 22.06 -15.54  15.68 F47 VEL 22 21.69 22.38 3570 3601 21.38 22.69 3554 3617
              0000020007 3401126040 0765570165 7260006000 0000537554 0004710000 4000014000 0000000000 4000040000
              4446720022 7774000005 0000000000 0070000000
00:05:33.421  AA103   N     0000 0000 3585 21.50 -15.18  15.26 F47 VEL 22 21.13 21.81 3569 3601 20.81 22.13 3553 3617
              0000020007 3400525400 0750270320 7250005600 0000537554 0004710000 4000014000 0000000000 4000040000
              4647300026 7774000066 0000000000 0174000000
00:05:33.423  AA107   N     0000 0000 3585 20.94 -14.77  14.85 F47 VEL 21 20.56 21.25 3568 3601 20.25 21.56 3552 3617
              0000020007 3400524740 0733270471 7260005300 0000537554 0004710000 4000014000 0000007000 4000040000
              4647620050 7774000037 0000000000 0274000000
00:05:33.335 1SECTOR TIME
             1TARGET RPT          4091   20.13 RADAR        7 4093   22.44 RADAR        7 0002   24.44 RADAR        5
                                  0015   24.50 RADAR        1 4033   26.75 RADAR        2
00:05:33.453 1SECTOR TIME
00:05:33.593 1SECTOR TIME
00:05:33.750 1SECTOR TIME
00:05:33.990  AA132   N     0000 0000 0000 26.75  00.03  26.76 F47 VEL 22 26.38 27.06 4081 0014 26.06 27.38 4067 0029
              0000022007 0000132600 1530200010 7600400000 0000540424 1004710000 4000012000 0000000000 4000040000
              4250100040 7764000031 0000000000 0054000000
00:05:33.992  AA130   N     0000 0000 0003 22.44  00.11  22.44 F47 VEL 23 22.06 22.75 4083 0018 21.75 23.06 4067 0034
              0000020007 0001526340 1316000035 7600000700 0000540673 0004710000 4000014000 0000000000 4000040000
              4250200031 7774000017 0000000000 0264000000
00:05:33.992  AA131   N     0000 0000 0002 24.44  00.11  24.46 F47 VEL 22 24.06 24.75 4083 0017 23.75 25.06 4069 0032
              0000022007 0001130340 1416700033 7610400300 0000540673 1004710000 4000012000 0000000000 4000040000
              4250320042 7764000070 0000000000 0164000000
00:05:33.994  AA129   N     0000 0000 0003 20.13  00.10  20.12 F47 VEL 23 19.75 20.44 4082 0019 19.44 20.75 4066 0036
              0000022007 0001524100 1203700032 7600000600 0000540673 0004710000 4000014000 0000000000 4000040000
              4250420070 7774000062 0000000100 0350000000
00:05:33.914 1SECTOR TIME
             1TARGET RPT          0013   20.25 RADAR        7 0012   22.25 RADAR        7 0012   24.25 RADAR        7
                                  0009   26.31 RADAR        7
00:05:34.031 1SECTOR TIME
00:05:34.187 1SECTOR TIME
```

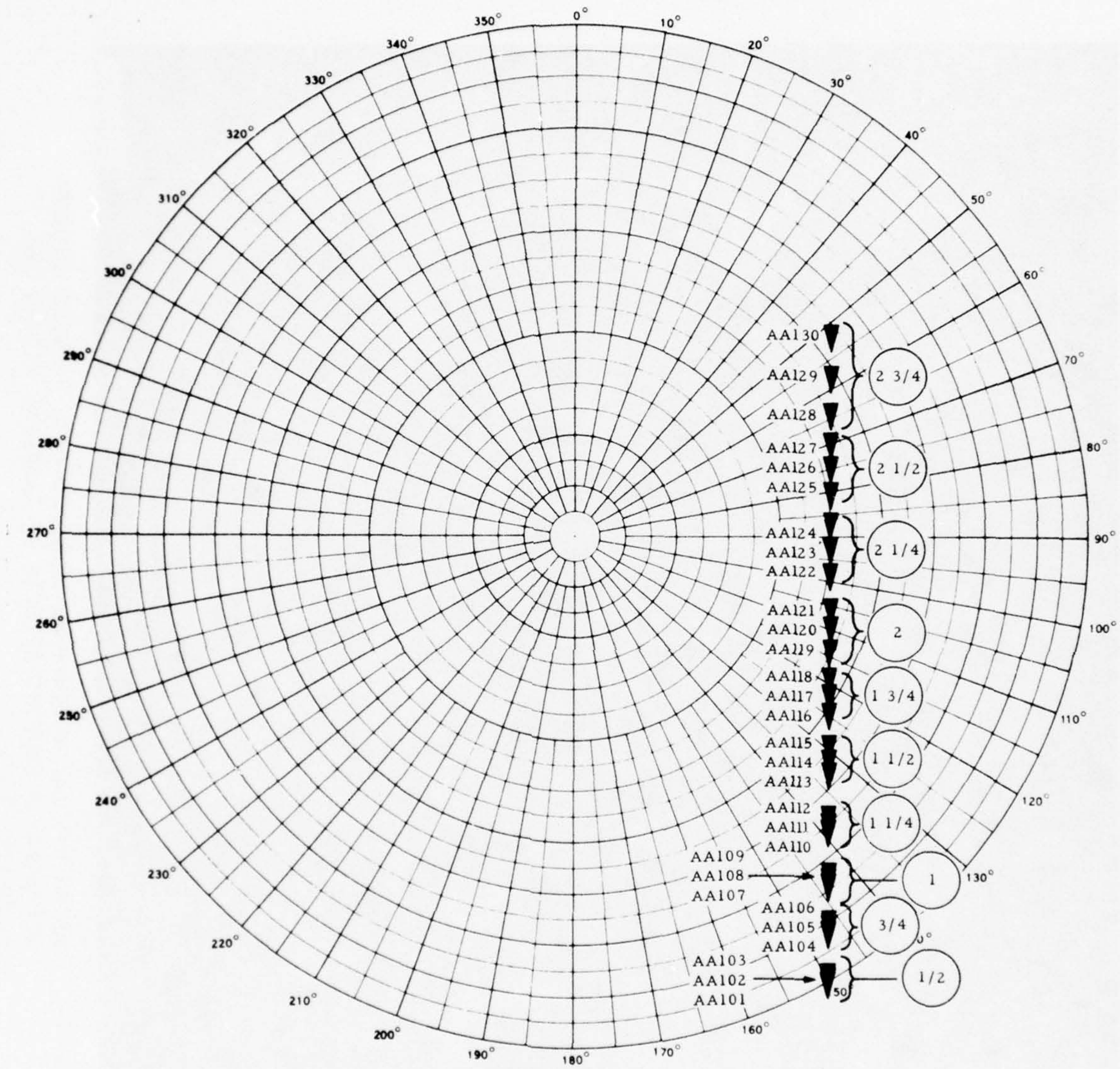
K61
001

3/4

1/2

76-6-22

FIGURE 22. UNISERVO VIc PRINTOUT, RADAR-ONLY TRACKING, RBS SCENARIO 001



SCENARIO 003: 30 TARGETS FLYING 30 nmi ABEAM OF THE RADAR, 225 KNOTS, *HEADING 180°, IN TRAIL SEPARATIONS* VARYING FROM 1/2 to 2 3/4 nmi, IN FORMATIONS OF 3 TARGETS WITH 3 - nmi SEPARATION BETWEEN GROUPS; TARGETS ARE DISCRETE BEACON WITH RADAR REINFORCEMENT. TRACKS ARE STARTED FROM STORED FLIGHT PLANS.

76-6-23

SCENARIO 004: SAME AS 003, EXCEPT RADAR ONLY

FIGURE 23. RBS SCENARIO 003/004--MINIMUM AZIMUTH SEPARATION EVALUATION

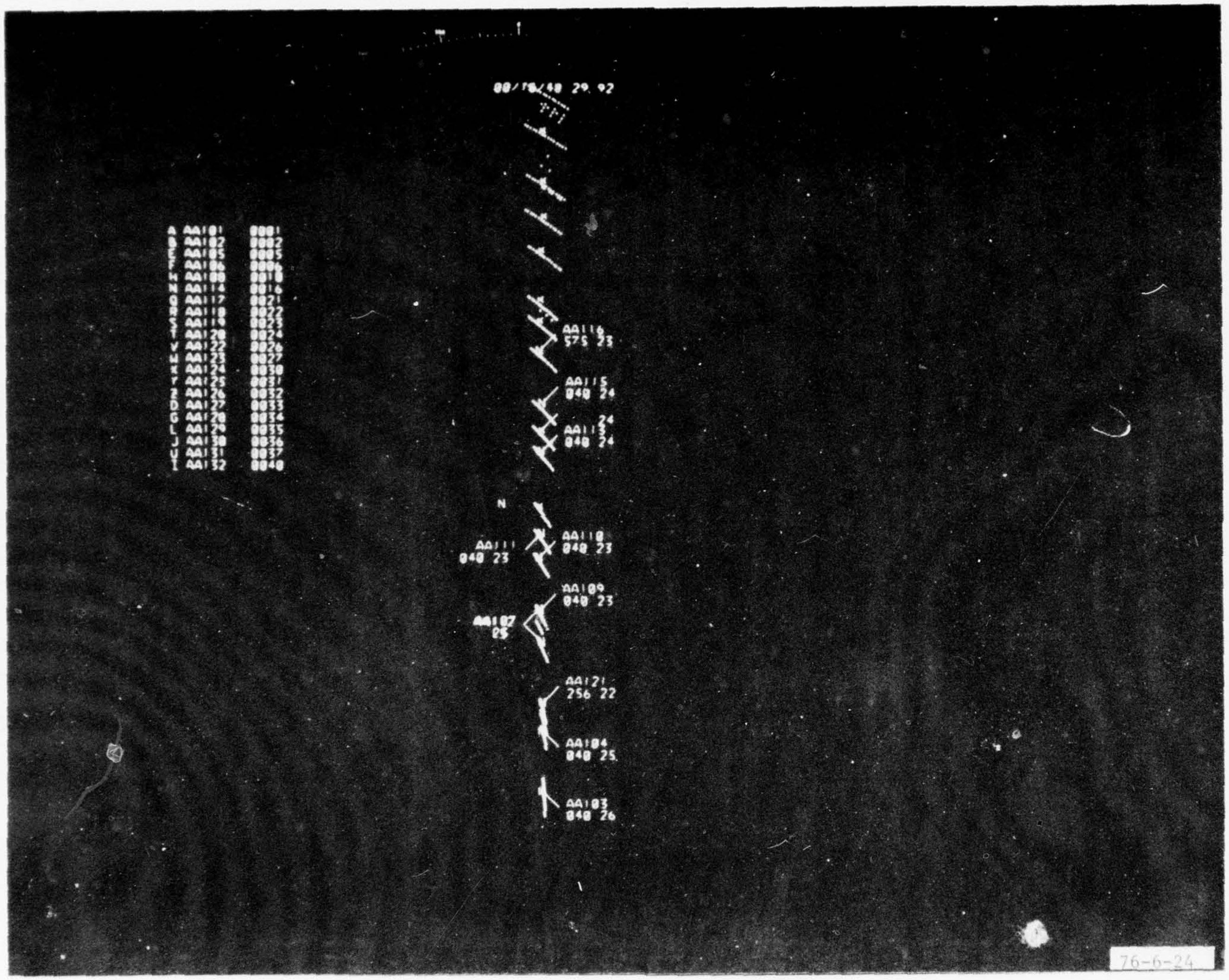


FIGURE 24. RADAR DISPLAY PHOTO--RBS SCENARIO 003, VARIOUS AZIMUTH SEPARATIONS SHOWING EFFECTS OF GARBLING WITHIN ONE BEAMWIDTH (4°)

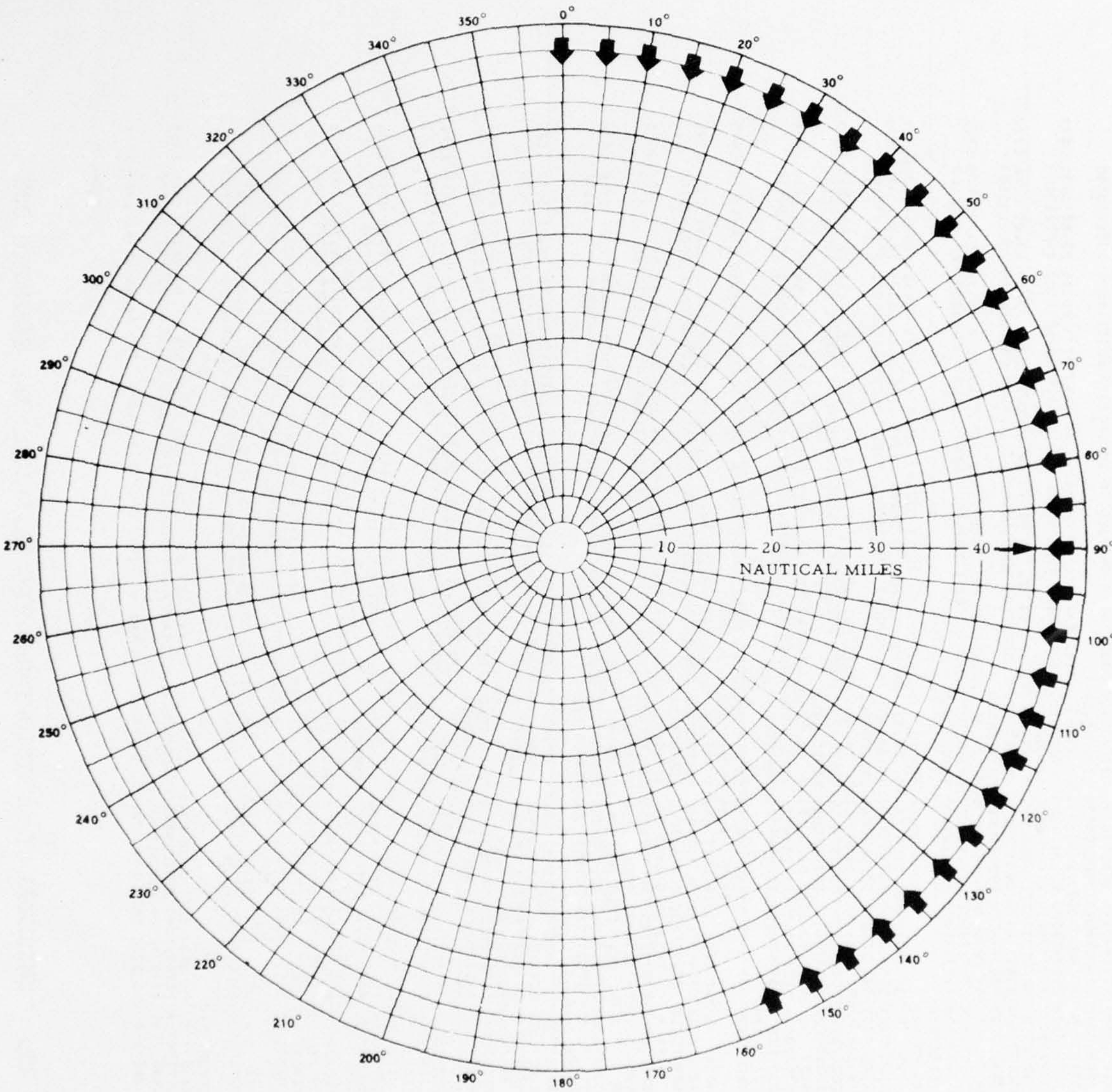
```
             0000022004 0551433440 0566014376 2330000400 0000170233 0402100376 0000402377 0010210000 7001770100
             4234420040 0460210042 0000000000 0700000000
00:15:15.351 AA118   B 040 0022 0022 0661 29.25  24.83  15.41 F47 VEL 21 28.88 29.56 0647 0674 28.56 29.88 0633 0688
             0000020004 0512535200 0755014325 7040077100 0000212601 0004700000 0002214000 0010010000 3002230100
             4234500022 7777776024 0000000000 0330000000
00:15:16.353   AA117 B 040 0021 0021 0694 28.38  24.86  13.73 F47 VEL 21 28.00 28.69 0680 0708 27.69 29.00 0666 0722
             0000020004 0533134300 0657214335 7040077500 0000212601 0004700000 0002114000 0010010000 3002130100
             4234600023 7777776025 0000000000 0214000000
00:15:15.355 AA116   B 040 0020 0020 0734 27.63  24.96  11.89 F47 VEL 23 27.25 27.94 0719 0748 26.94 28.25 0705 0762
             0000020004 0557133500 0574514367 6770000000 0000212601 0004700000 0002014000 0010010000 3002030100
             4234720024 7777776026 0000000000 0330000000
00:15:16.304 1SECTOR TIME
             1TARGET RPT          1142S  25.44 0007-3 040-3 7 1210S  26.13 0006-3 000-0 7 1227S  26.31 0505-3 256-3 7
00:15:16.492 AA115   B 040 0017 0017 0804 26.44  24.93  08.73 F47 VEL 22 26.06 26.75 0789 0818 25.75 27.06 0775 0833
             0000020004 0622132340 0427214357 7010477600 0000213042 0004700000 0001712000 0010010000 3001730100
             4235000025 7757766027 0000000000 0460000000
00:15:16.494   AA114 B 040 0016 0016 0840 26.00  24.96  07.26 F47 VEL 22 25.63 26.31 0825 0854 25.31 26.63 0811 0869
             0000020004 0644132000 0350314366 7010077600 0000213042 0004700000 0001614000 0010010000 3001630100
             4235100026 7777776030 0000000000 0360000000
00:15:16.496 AA113   B 040 0015 0015 0876 25.63  24.97  05.76 F47 VEL 23 25.25 25.94 0861 0890 24.94 26.25 0846 0905
             0000020004 0636131500 0272214371 6770477600 0000213042 0004700000 0001514000 0010010000 3001530100
             4235200027 7377576031 0000000000 0444000000
00:15:16.445 1SECTOR TIME
             1TARGET RPT          1751S  26.56 0004-3 040-3 7 1310S  27.69 0307-3 000-0 7 1327S  27.94 0206-3 000-0 7
                                  1343S  28.19 0001-3 040-2 7
00:15:16.634 AA112   B 040 0014 0014 0952 25.19  25.01  02.79 F47 VEL 21 24.81 25.50 0937 0966 24.50 25.81 0922 0981
             0000020004 0734131140 0131114402 7030000100 0000213260 0004700000 0001414000 0010010000 3001430100
             4435320030 7777776032 0000000000 0524000000
00:15:16.636   AA111 B   0013 0000 0982 25.13  25.05  01.61 F47 VEL 23 24.75 25.44 0967 0996 24.44 25.75 0952 1011
             0000020004 0753131100 0063314415 6760400200 0000213260 0004710000 0001314000 0010010000 4000040000
             4435520031 7577554033 0000000000 0264000000
00:15:16.638 AA110   B 040 0012 0013 1010 24.94  24.96  00.53 F47 VEL 19 24.56 25.25 0995 1024 24.25 25.56 0980 1039
             0000020004 0771130740 0020714366 7110077600 0000213260 0004700000 0001214000 0010010000 3001330100
             4235720032 7776376034 0000000000 0554000000
00:15:16.601 1SECTOR TIME
00:15:16.777 AA170   B      0020 0170 1092 25.19  25.02 -02.66 F47 VEL 15 24.81 25.50 1077 1106 24.50 25.81 1062 1121
             0000020004 1042131140 7652514405 7250400100 0000213500 0004700000 0003614000 0010000000 2017040000
             4436020045 0374576007 0000000000 0240000000
00:15:16.779   AA109 B 040 0011 0011 1114 25.25  25.01 -03.51 F35 VEL 08 24.88 25.56 1099 1128 24.56 25.88 1084 1143
             0000072004 1055131200 7017514402 7510000000 0000213500 0003500000 0001106000 0010010000 3001130100
             4436220033 6417205035 0000000000 0604000000
00:15:16.781 AA107   B 040 0007 0007 1146 25.50  25.03 -04.78 F47 VEL 26 25.13 25.81 1131 1160 24.81 26.13 1116 1175
             0000020004 1075131400 7746714407 5660000300 0000213500 0004700000 0000714000 0010010000 3000730100
             4236420035 3774572037 0000000000 0650000000
00:15:16.742 1SECTOR TIME
00:15:16.919   AA106 B 040 0006 0006 1207 26.06  25.06 -07.26 F47 VEL 20 25.69 26.38 1192 1221 25.38 26.69 1178 1236
             0000020004 1133532040 7427414420 7060400300 0000213741 0004700000 0000614000 0010010000 3000630100
             4436020036 5778776040 0000000000 0444000000
00:15:16.921 AA101   B (256)0025 0305 1229 26.31  25.01 -08.18 F47 VEL 25 25.94 26.63 1214 1243 25.63 26.94 1200 1258
             0000020004 1146532240 7372114403 6700000000 0000213741 0004700000 0002514000 0010010000 3050531126
             4636720017 7777776021 0000000000 0564000000
00:15:16.935 TRIAL TRK 0 0017 0775 28.44  26.40  10.59 F10 VEL 54 27.94 28.88 0758 0792 00.00 00.00 0000 0000
             0000020020 0603434340 0522713147 1770012400 0000201524 4001000041 0001700377 0000210000 3001730100

00:15:16.333 TRIAL TRK 0 0017 0740 25.81  23.52  10.65 F10 VEL 54 25.31 26.25 0728 0764 00.00 00.00 0000 0000
             0000020000 0505031640 0525213606 2040060000 0000201524 4401000041 0001710376 0000210000 3001730100

00:15:16.880 1SECTOR TIME
00:15:17.062 AA103   B      0003 0307 1310 27.69  25.06 -11.81 F47 VEL 23 27.31 28.00 1295 1324 27.00 28.31 1281 1338
             0000020004 1217133540 7205714417 6760000200 0000214157 0004700000 0000314000 0010010000 2030740000
             4437420041 7777776004 0000000000 0074000000
00:15:17.000   AA101 B 040 0001 0001 1343 28.19  24.86 -13.24 F47 VEL 24 27.81 28.50 1329 1357 27.50 28.81 1315 1371

                                                                                                         76-6-25
```

FIGURE 25. UNISERVO VIc PRINTOUT SHOWING GARBLING, RBS SCENARIO 003



SCENARIO 008 : 32 TARGETS SEPARATED BY 5° OF AZIMUTH, INBOUND FROM 40 N. MILES, DISCRETE BEACON AND RADAR.

SCENARIO 009 : AS 008, EXCEPT RADAR ONLY, RADAR REPLY STRENGTH VARIES FROM 0 TO 31 DB, WITH INCREASING AZIMUTH.

76-6-26

FUGURE 26. RBS SCENARIO 008--MINIMUM AZIMUTH SEPARATION EVALUATION

```
00:00:27.031 1SECTOR TIME
00:00:27.171 1SECTOR TIME
00:00:27.328 1SECTOR TIME
00:00:27.468 1SECTOR TIME
00:00:27.609 1SECTOR TIME
00:00:27.765 1SECTOR TIME
00:00:27.906 1SECTOR TIME
             1TARGET RPT    4095S  38.56 0001-3 040-3 0 0054S  38.63 0002-3 040-3 0
00:00:28.046 1SECTOR TIME
             1TARGET RPT    0110S  38.56 0003-3 040-3 0 0171S  38.56 0004-3 040-3 0
00:00:28.203 1SECTOR TIME
             1TARGET RPT    0226S  38.63 0005-3 040-3 0 0282S  38.56 0006-3 040-3 0 0341S  38.56 0007-3 040-3 0
00:00:28.343 1SECTOR TIME
             1TARGET RPT    0396S  38.56 0010-3 040-3 0 0454S  38.63 0011-3 040-3 5
00:00:28.507 1SECTOR TIME
             1TARGET RPT    0511S  38.56 0012-3 040-3 3 0570S  38.56 0013-3 040-3 0
00:00:28.640 1SECTOR TIME
             1TARGET RPT    0626S  38.56 0014-3 040-3 4 0682S  38.31 0015-3 040-3 7 0739S  38.31 0016-3 040-3 7
00:00:28.796 1SECTOR TIME
             1TARGET RPT    0793S  38.31 0017-3 040-3 7 0854S  38.31 0020-3 040-3 7
00:00:28.937 1SECTOR TIME
             1TARGET RPT    0914S  38.25 0021-3 040-3 3 0970S  38.31 0022-3 040-3 7
00:00:29.078 1SECTOR TIME
             1TARGET RPT    1022S  38.31 0023-3 040-3 7 1073S  38.31 0024-3 040-3 7
00:00:29.234 1SECTOR TIME
             1TARGET RPT    1135S  38.25 0025-3 040-3 7 1191S  38.31 0026-3 040-3 7
00:00:29.375 1SECTOR TIME
             1TARGET RPT    1248S  38.25 0027-3 040-3 4 1263   38.38 RADAR        1 1308S  38.25 0030-3 040-3 7
                            1367S  38.25 0031-3 040-3 6
00:00:29.515 1SECTOR TIME
             1TARGET RPT    1423S  38.25 0032-3 040-3 5 1477S  38.31 0033-3 040-3 7
00:00:29.671 1SECTOR TIME
             1TARGET RPT    1534S  38.25 0034-3 040-3 7 1531S  38.25 0035-3 040-3 7
00:00:29.812 1SECTOR TIME
             1TARGET RPT    1648S  38.31 0036-3 040-3 7 1705S  38.25 0037-3 040-3 7
00:00:29.957 1SECTOR TIME
             1TARGET RPT    1764S  38.25 0040-3 040-3 7
00:00:30.109 1SECTOR TIME
00:00:30.250 1SECTOR TIME
             1TARGET RPT    2081   57.88 RADAR        7 2081S  59.06 0000-3 000-0 0
00:00:30.390 1SECTOR TIME
00:00:30.546 1SECTOR TIME
00:00:30.687 1SECTOR TIME
00:00:30.843 1SECTOR TIME
00:00:30.984 1SECTOR TIME
00:00:31.140 1SECTOR TIME
00:00:31.281 1SECTOR TIME
00:00:31.414 1SECTOR TIME
00:00:31.578 1SECTOR TIME
00:00:31.718 1SECTOR TIME
00:00:31.851 1SECTOR TIME
00:00:32.015 1SECTOR TIME
00:00:32.156 1SECTOR TIME
00:00:32.289 1SECTOR TIME
00:00:32.453 1SECTOR TIME
00:00:32.593 1SECTOR TIME
             1TARGET RPT    4095S  38.31 0001-3 040-3 0 0056S  38.25 0002-3 040-3 0
00:00:32.750 1SECTOR TIME
             1TARGET RPT    0112S  38.25 0003-3 040-3 0 0171S  38.25 0004-3 040-3 0
00:00:32.890 1SECTOR TIME
             1TARGET RPT    0226S  38.25 0005-3 040-3 0 0283S  38.31 0006-3 040-3 1 0341S  38.31 0007-3 040-3 0
00:00:33.023 1SECTOR TIME                                                                          76-6-27
```

FIGURE 27. UNISERVO VIc PRINTOUT SHOWING GARBLE-FREE TRACKING AT AZIMUTH SEPARATION GREATER THAN ONE BEAMWIDTH, RBS SCENARIO 008

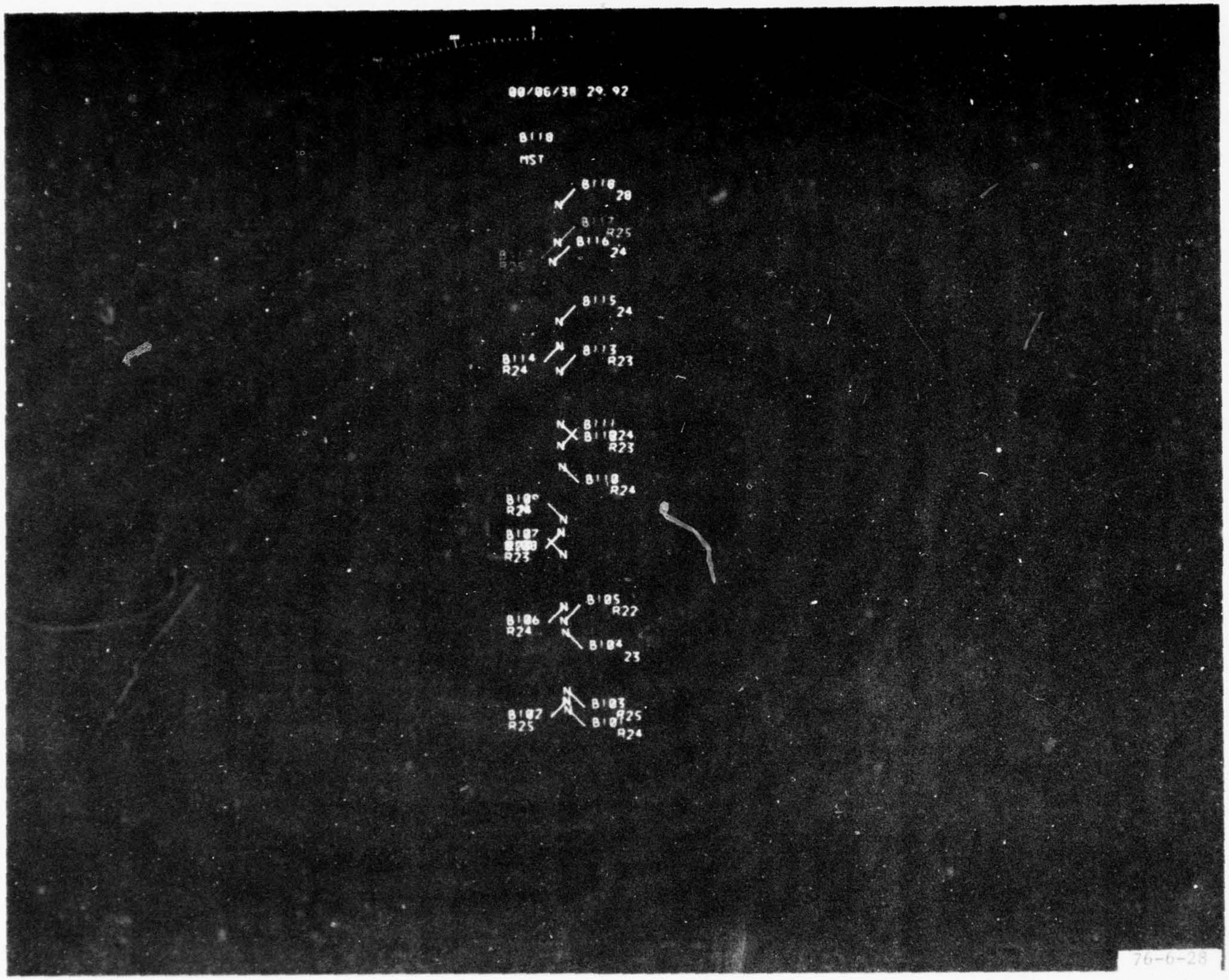
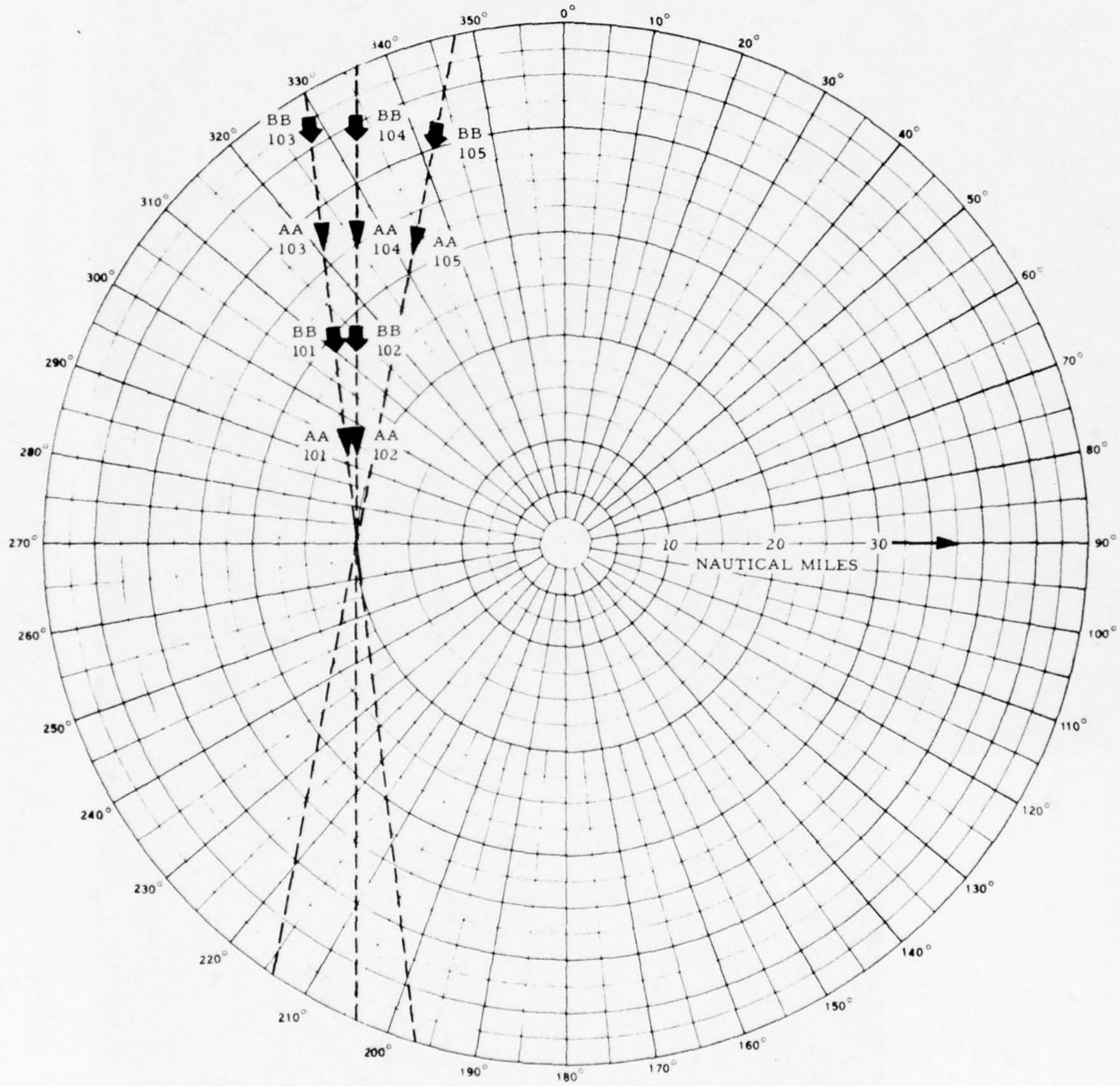


FIGURE 28. RADAR DISPLAY PHOTO--RBS SCENARIO 004, VARIOUS AZIMUTH SEPARATIONS, RADAR-ONLY TARGETS, SUCCESSFULLY TRACKED WITHIN ONE BEAMWIDTH (1 1/2°)



SCENARIO 024 : 10 TARGETS CONVERGING ALONG 2 OR 3 TRACKS AT A POINT 20 N. MILES OUT ON THE 270° RADIAL, IN COMBINATIONS OF 2 AND 3 TARGETS, DISCRETE BEACON PLUS RADAR AND RADAR ONLY 225 KNOT AIRSPEED.

76-6-29

FIGURE 29. RBS SCENARIO 024--TRACK SWAP EVALUATION, CONVERGING TARGETS

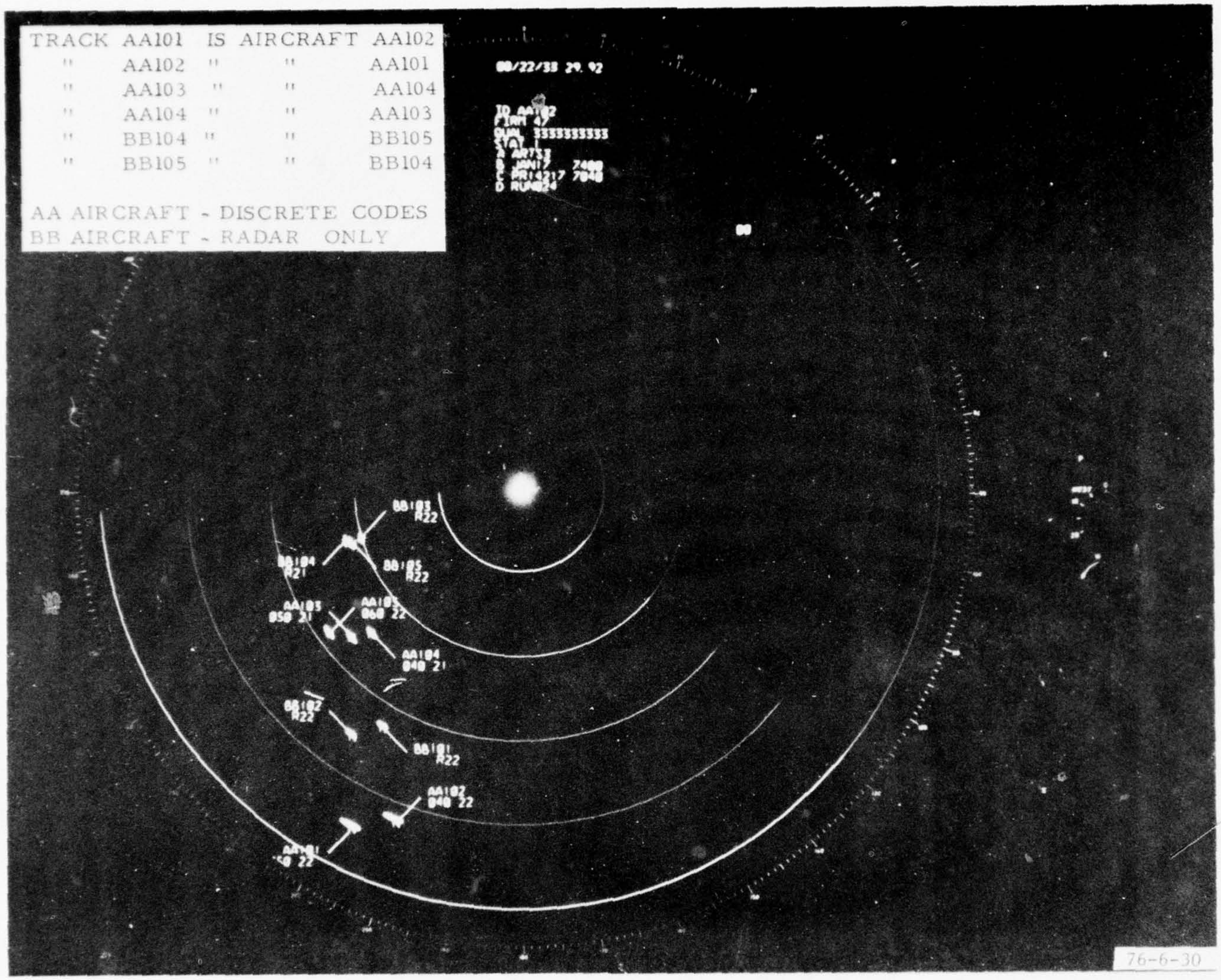


FIGURE 30. RADAR DISPLAY PHOTO--RBS SCENARIO 024 SHOWING BOTH DISCRETE BEACON AND RADAR-ONLY TRACK SWAPS

```
                 1TARGET RPT          2308S  39.13 0001-3 040-3 7 2372S  41.38 0002-3 050-3 7
00:22:08.257 1SECTOR TIME
                 1TARGET RPT          2429   30.19 RADAR        7 2430   32.75 RADAR        7
00:22:08.414 1SECTOR TIME
                 1TARGET RPT          2640S  22.31 0003-3 040-3 7
00:22:08.554 1SECTOR TIME
                 1TARGET RPT          2658S  24.94 0004-3 249-3 7 2700S  26.50 0005-3 060-3 6
00:22:08.757  BB102   B     0000 0000 2428 30.25 -16.65 -25.26 F47 VEL 23 29.88 30.56 2414 2441 29.56 30.88 2400 2455
              0000020004 2276136200 6327467530 7000400500 0000026120 0004710000 4000014000 0000000000 4000040000
              4217020050 7774000046 0000000000 1454000000
00:22:08.757   AA102 B 050 0002 0002 2371 41.88 -19.94 -36.80 F47 VEL 23 41.50 42.19 2359 2383 41.19 42.50 2347 2395
              0000020004 2241551700 5546106010 7000400400 0000026120 0004700000 0000214000 0010010000 3000230120
              4217120042 7777776037 0000000000 1710000000
00:22:08.759  AA101   B 040 0001 0001 2305 39.06 -15.05 -36.07 F47 VEL 23 38.69 39.38 2292 2317 38.38 39.69 2280 2329
              0000020004 2200547040 5575470761 7010001500 0000026120 0004700000 0000114000 0010010000 3000130100
              4217220040 7777777777 0000000000 1670000000
00:22:08.695 1SECTOR TIME
00:22:08.900   BB101 B     0000 0000 2476 32.75 -20.03 -25.89 F47 VEL 23 32.38 33.08 2462 2489 32.06 33.78 2449 2502
              0000020004 2326140600 6303265770 0770400200 0000026336 0004710000 4000014000 0000000000 4000040000
              4217320003 7774000002 0000000000 1610000000
00:22:08.851 1SECTOR TIME
                 1TARGET RPT          2968   19.63 RADAR        7 2956   20.44 RADAR        7 2971   20.63 RADAR        7
00:22:09.042  AA103   B 050 0005 0004 2657 24.94 -20.05 -14.83 F47 VEL 22 24.55 25.25 2642 2671 24.25 25.56 2627 2686
              0000020004 2460530740 7045305757 7020477000 0000026551 0004700000 0000514000 0010010000 3000430120
              4217420045 7777776012 0000000000 1050000000
00:22:09.042   AA104 B 040 0004 0003 2639 22.88 -17.99 -14.08 F47 VEL 22 22.50 23.19 2623 2654 22.19 23.50 2608 2670
              0000020004 2447526700 7075367001 7020000700 0000026551 0004700000 0000414000 0010010000 3000330100
              4217520044 7777776042 0000000000 1230000000
00:22:08.992 1SECTOR TIME
00:22:09.148 1SECTOR TIME
00:22:09.289 1SECTOR TIME
00:22:09.470  BB103   B     0000 0000 2966 19.67 -19.38 -03.18 F43 VEL 22 19.25 19.94 2949 2982 18.94 20.25 2932 2999
              0000022004 2713123300 7032266037 7010401000 0000027451 1004310000 4000006000 0000000000 4000040000
              4217720047 7004000003 0000000000 1134000000
00:22:09.470  BB105   B     0000 0000 2953 20.38 -20.09 -03.55 F47 VEL 24 20.00 20.69 2941 2974 19.59 21.00 2925 2991
              0000020064 2757124300 7616555750 6750400200 0000027451 0004710000 4000014000 0000000000 4000040000
              4420020025 7774000047 0000000000 0454000000
00:22:09.472   BB104 B     0000 0000 2972 19.19 -18.93 -02.93 F34 VEL 20 18.81 19.50 2954 2989 18.50 19.81 2937 3006
              0000022004 2716023140 7542065420 7160003300 0000737273 0403410372 4000000373 0000100000 4000040000
              4220220051 7400000050 0000000000 0774000000
00:22:09.429 1SECTOR TIME
00:22:09.585 1SECTOR TIME
00:22:09.726 1SECTOR TIME
00:22:09.867 1SECTOR TIME
00:22:10.041  TRIAL TRK 0 0000 3054 22.56 -22.34 -00.62 F11 VEL 20 22.13 22.94 3036 3071 00.00 00.00 0000 0000
              0000020000 2767026440 7754164565 0160071200 0001027451 4001100047 0000000373 0000100000 4000040000

00:22:10.041  TRIAL TRK 0 0000 3118 18.94 -18.99 01.36 F11 VEL 19 18.50 19.31 3098 3137 00.00 00.00 0000 0000
              0000020000 3027022740 0753306430 0640002000 0001027451 4401100047 0000000372 0000100000 4000040000

00:22:10.023 1SECTOR TIME
00:22:10.164 1SECTOR TIME
00:22:10.295 1SECTOR TIME
00:22:10.460 1SECTOR TIME
00:22:10.591 1SECTOR TIME
00:22:10.734 1SECTOR TIME
00:22:10.896 1SECTOR TIME
00:22:11.031 1SECTOR TIME
00:22:11.195 1SECTOR TIME
00:22:11.324 1SECTOR TIME
00:22:11.492 1SECTOR TIME
00:22:11.632 1SECTOR TIME
```

76-6-31

FIGURE 31. UNISERVO VIc PRINTOUT SHOWING TRACK SWAPS, RBS SCENARIO 024

swap tests with the improved program can be found in a MITRE report MTR-7300 entitled "Technical Performance of the ARTS III Tracking Function."

TRACKING LIMITS IN TURNS.

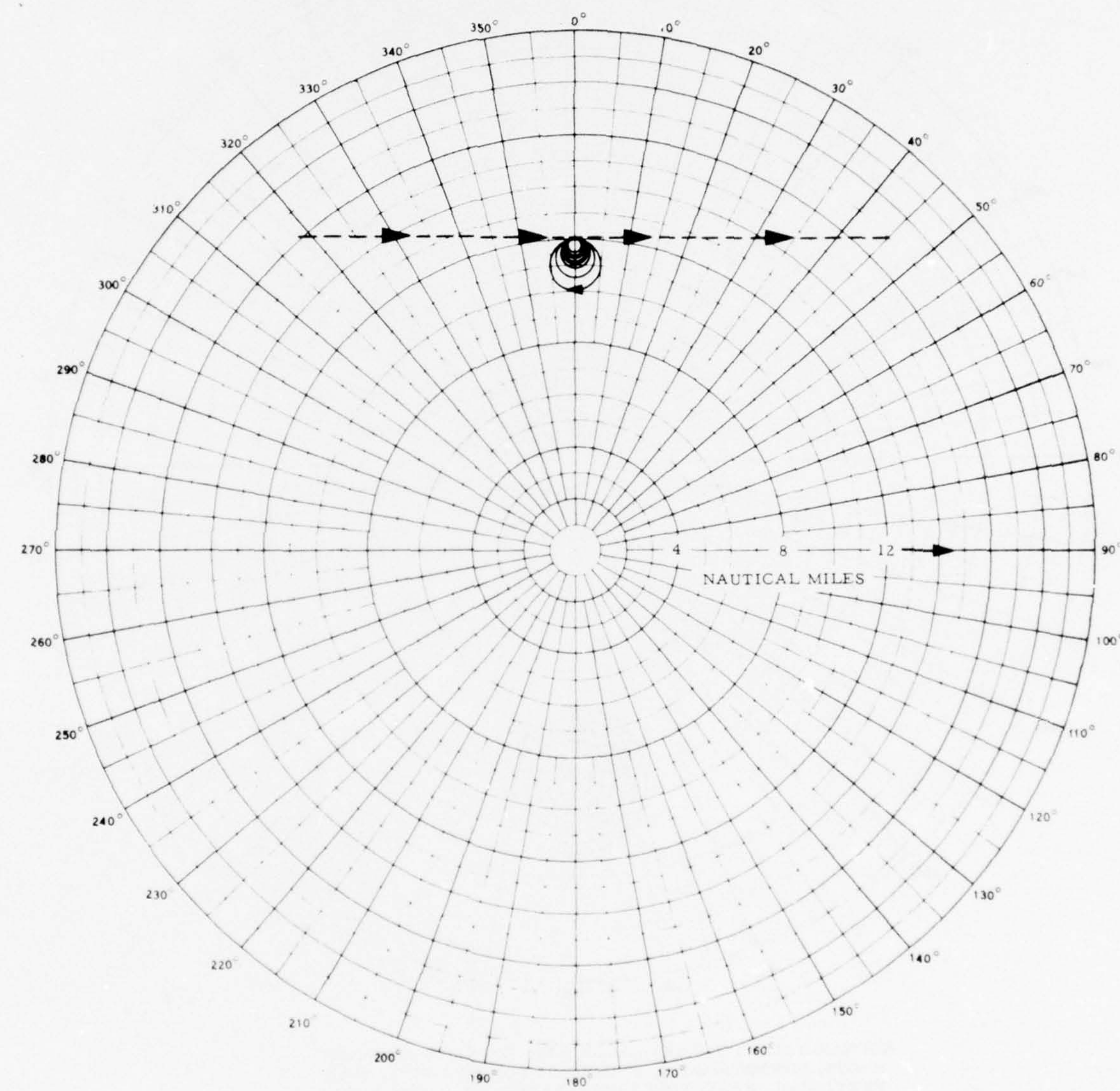
It was verified that as long as the round reliability was unity, track retention in turns was solid, even during abnormal turn rates. Figure 32 depicts RBS scenario 018 during which turn rates as high as 10°/second were tracked without a track-coast condition developing; target airspeed was maintained at 180 knots. The displacement of the target in relation to the tracking bin dimensions is the prime factor for track retention in turns. Figure 33, RBS scenarios 022 and 023, demonstrate this. A single target was maintained at a constant turn rate of 3°/second and accelerated at a constant rate (45 knots/min) from an initial velocity of 100 knots to a velocity high enough to cause loss of correlation and track coast. At unity round reliability, this did not occur for the beacon target until a velocity in excess of 300 knots was achieved. Figure 34, UNISERVO VIc printout, shows this event. Figure 35, another UNISERVO VIc printout, shows a similar radar-only target commencing to fail to correlate at 360 knots. Any degeneration in round reliability, as was observed in live testing, seriously degrades this performance.

TRACKING AT LIMIT SPEEDS.

Figure 36 depicts RBS scenario 025 during which beacon targets were accelerated to determine the velocity at which straight-line tracking would fail to correlate and a coast condition develop. As shown in figure 37, a radar display photo, this occurred at 700 knots.

TRACKING AT CLOSE RANGES.

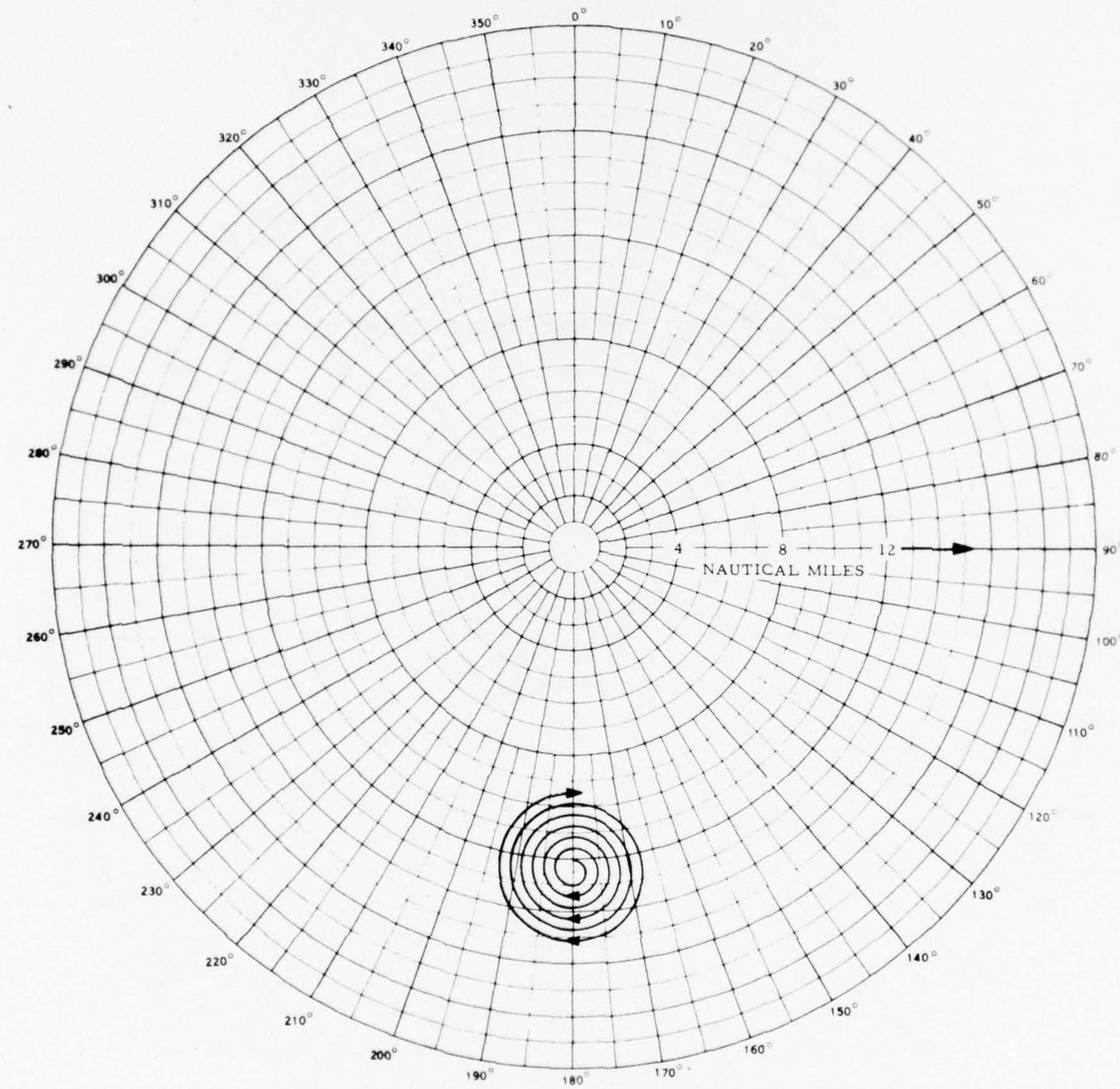
Maximum position errors equivalent to the height of the target were experienced because slant range rather than ground range was processed and displayed.



SCENARIO 018 : 8 TARGETS, 180 KNOTS, VARIOUS TURN RATES FROM 3 TO 10° / SEC., DISCRETE BEACON AND RADAR, TURN CENTERS ABOUT A POINT 12 nmi OUT ON THE 360° RADIAL

76-6-32

FIGURE 32. RBS SCENARIO 018---TARGETS IN VARIOUS TURN RATES



SCENARIO 022 : 1 TARGET, ACCELERATING FROM 100 TO 600 KNOTS, (45KNOTS/MIN.), CLIMBING FROM 2 TO 99.9 K (1500 FEET/MIN.), EXECUTING A SPIRAL TURN AT A CONSTANT RATE OF 3°/SEC, RADAR AND DISCRETE BEACON.

SCENARIO 023 : AS 022 EXCEPT RADAR ONLY.

76-6-33

FIGURE 33. RBS SCENARIO 022/023 - TURNING TRACK EVALUATION, 3°/SECOND TURN RATES

```
00:06:20.453 1SECTOR TIME
00:06:20.593 1SECTOR TIME
X 00:06:20.822  AA101   B    0001 0001 1617 16.38  10.04 -12.90 F46 VEL 30 16.00 16.69 1598 1635 15.69 17.00 1580 1654
               0000022004 1450420300 7143105012 6610073600 0000152172 0404600372 0000106000 0010110000 7000170206
               4212320001 7773775777 0000000000 0454000000
00:06:20.750 1SECTOR TIME
             1TARGET RPT          2081S  59.06 0000-3 000-0 0 2081   57.88 RADAR       7
00:06:20.890 1SECTOR TIME
00:06:21.046 1SECTOR TIME
00:06:21.187 1SECTOR TIME
00:06:21.328 1SECTOR TIME
00:06:21.484 1SECTOR TIME
00:06:21.625 1SECTOR TIME
00:06:21.765 1SECTOR TIME
00:06:21.921 1SECTOR TIME
00:06:22.062 1SECTOR TIME
00:06:22.218 1SECTOR TIME
00:06:22.359 1SECTOR TIME
00:06:22.515 1SECTOR TIME
00:06:22.656 1SECTOR TIME
00:06:22.796 1SECTOR TIME
00:06:22.953 1SECTOR TIME
00:06:23.093 1SECTOR TIME
00:06:23.234 1SECTOR TIME
00:06:23.390 1SECTOR TIME
00:06:23.531 1SECTOR TIME
00:06:23.664 1SECTOR TIME
00:06:23.828 1SECTOR TIME
00:06:23.968 1SECTOR TIME
00:06:24.101 1SECTOR TIME
00:06:24.265 1SECTOR TIME
00:06:24.398 1SECTOR TIME
00:06:24.539 1SECTOR TIME
00:06:24.703 1SECTOR TIME
00:06:24.853 1SECTOR TIME
00:06:25.000 1SECTOR TIME
             1TARGET RPT          1640S  15.63 0001-3 089-3 7
00:06:25.132 1SECTOR TIME
00:06:25.296 1SECTOR TIME
X 00:06:25.527  AA101   B    0001 0001 1630 16.56  09.89 -13.26 F42 VEL 30 16.19 16.88 1611 1648 15.88 17.19 1593 1667
               0000022004 1457020440 7127504743 6610073600 0000152172 0404200372 0000102000 0010210000 7000170206
               4212420001 7763771777 0000000000 0460000000
00:06:25.437 1SECTOR TIME
             1TARGET RPT          2080S  59.06 0000-3 000-0 0 2081   57.88 RADAR       7
00:06:25.570 1SECTOR TIME
00:06:25.726 1SECTOR TIME
00:06:25.867 1SECTOR TIME
00:06:26.007 1SECTOR TIME
00:06:26.164 1SECTOR TIME
00:06:26.304 1SECTOR TIME
00:06:26.445 1SECTOR TIME
00:06:26.601 1SECTOR TIME
00:06:26.742 1SECTOR TIME
00:06:26.898 1SECTOR TIME
00:06:27.039 1SECTOR TIME
00:06:27.195 1SECTOR TIME
00:06:27.335 1SECTOR TIME
00:06:27.476 1SECTOR TIME
00:06:27.632 1SECTOR TIME
00:06:27.773 1SECTOR TIME
00:06:27.914 1SECTOR TIME
00:06:28.070 1SECTOR TIME
```

1K60

022

3°/sec

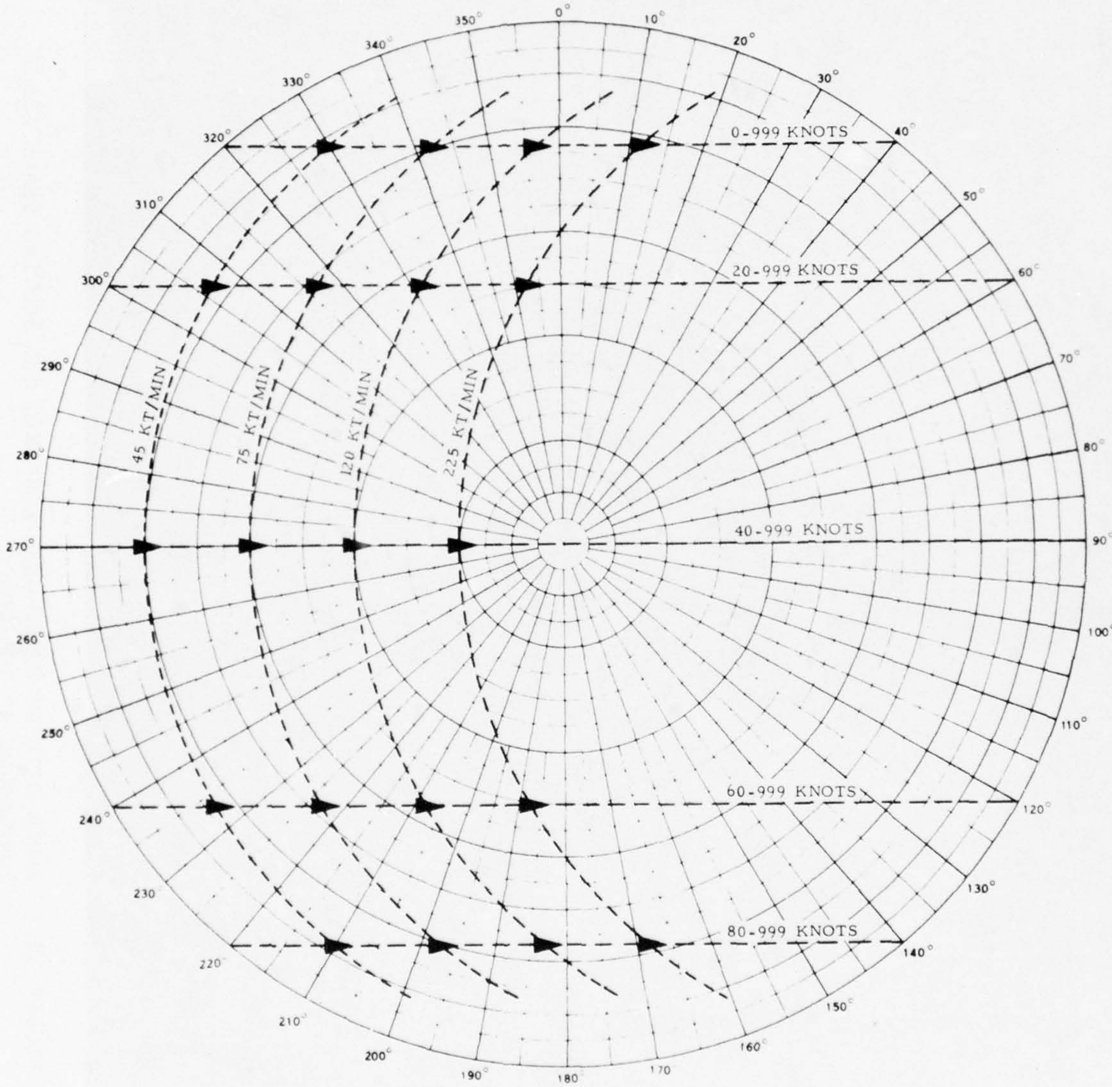
76-6-34

FIGURE 34. UNISERVO VIc PRINTOUT SHOWING TRACK COAST AT 300 KNOTS, 40° OF BANK, BEACON TARGET, RBS SCENARIO 022, 100-PERCENT ROUND RELIABILITY

```
00:07:24.664 1SECTOR TIME
00:07:24.804 1SECTOR TIME
00:07:24.960 1SECTOR TIME
00:07:25.101 1SECTOR TIME
00:07:25.242 1SECTOR TIME
00:07:25.398 1SECTOR TIME
00:07:25.539 1SECTOR TIME
00:07:25.695 1SECTOR TIME
00:07:25.835 1SECTOR TIME
00:07:25.976 1SECTOR TIME
00:07:26.132 1SECTOR TIME
00:07:26.273 1SECTOR TIME
00:07:26.414 1SECTOR TIME
00:07:26.570 1SECTOR TIME
00:07:26.710 1SECTOR TIME
00:07:26.843 1SECTOR TIME
00:07:26.984 1SECTOR TIME
00:07:27.140 1SECTOR TIME
             1TARGET RPT          1560   12.13 RADAR        7
00:07:27.304 1SECTOR TIME
00:07:27.445 1SECTOR TIME
00:07:27.601 1SECTOR TIME
00:07:27.765  38101   B       0000 0000 1564 11.75  07.96 -08.67 F47 VEL 36 11.38 12.06 1541 1586 11.06 12.38 1518 1609
             0000020004 1416113600 7352403765 1350005600 0000313647 000471C000 400C014000 0000000000 4000040000
             4240300040 7774000037 0000000000 0520000000
00:07:27.742 1SECTOR TIME
             1TARGET RPT          2081S  59.06 0000-3 000-0 0 2080   57.88 RADAR        7
00:07:27.875 1SECTOR TIME
00:07:28.039 1SECTOR TIME
00:07:28.171 1SECTOR TIME
00:07:28.312 1SECTOR TIME
00:07:28.468 1SECTOR TIME
00:07:28.609 1SECTOR TIME
00:07:28.773 1SECTOR TIME
00:07:28.906 1SECTOR TIME
00:07:29.046 1SECTOR TIME
00:07:29.203 1SECTOR TIME
00:07:29.343 1SECTOR TIME
00:07:29.500 1SECTOR TIME
00:07:29.640 1SECTOR TIME
00:07:29.781 1SECTOR TIME
00:07:29.937 1SECTOR TIME
00:07:30.078 1SECTOR TIME
00:07:30.218 1SECTOR TIME
00:07:30.375 1SECTOR TIME
00:07:30.515 1SECTOR TIME
00:07:30.656 1SECTOR TIME
00:07:30.812 1SECTOR TIME
00:07:30.953 1SECTOR TIME
00:07:31.093 1SECTOR TIME
00:07:31.250 1SECTOR TIME
00:07:31.390 1SECTOR TIME
00:07:31.531 1SECTOR TIME
00:07:31.687 1SECTOR TIME
00:07:31.843 1SECTOR TIME
             1TARGET RPT          1532   12.25 RADAR        7
00:07:31.984 1SECTOR TIME
00:07:32.125 1SECTOR TIME
00:07:32.281 1SECTOR TIME
00:07:32.472  88101   8       0000 0000 1539 11.63  08.16 -08.25 F46 VEL 36 11.25 11.94 1516 1561 10.94 12.25 1493 1584
             0000022004 1401413500 7370004052 1350005600 0000313647 0004610372 4000006000 0000100000 4000040000
             4240420040 7770000037 0000000000 0524000000
                                                                                                        76-6-35
```

K60
023
3°/sec

FIGURE 35. UNISERVO VIc PRINTOUT SHOWING TRACK COAST AT 360 KNOTS, 45°BANK RADAR-ONLY TARGET, RBS SCENARIO 023, 100-PERCENT ROUND RELIABILITY



SCENARIO 025 : 20 TARGETS, GROUPS OF 5, ACCELERATING AT RATES OF 45, 75, 120, AND 225 KNOTS/MIN., INITIAL VELOCITIES VARY FROM 0 TO 80 KNOTS, TERMINAL VELOCITY 999 KNOTS.

76-6-36

FIGURE 36. RBS SCENARIO 025--LIMIT TRACK-SPEED EVALUATION

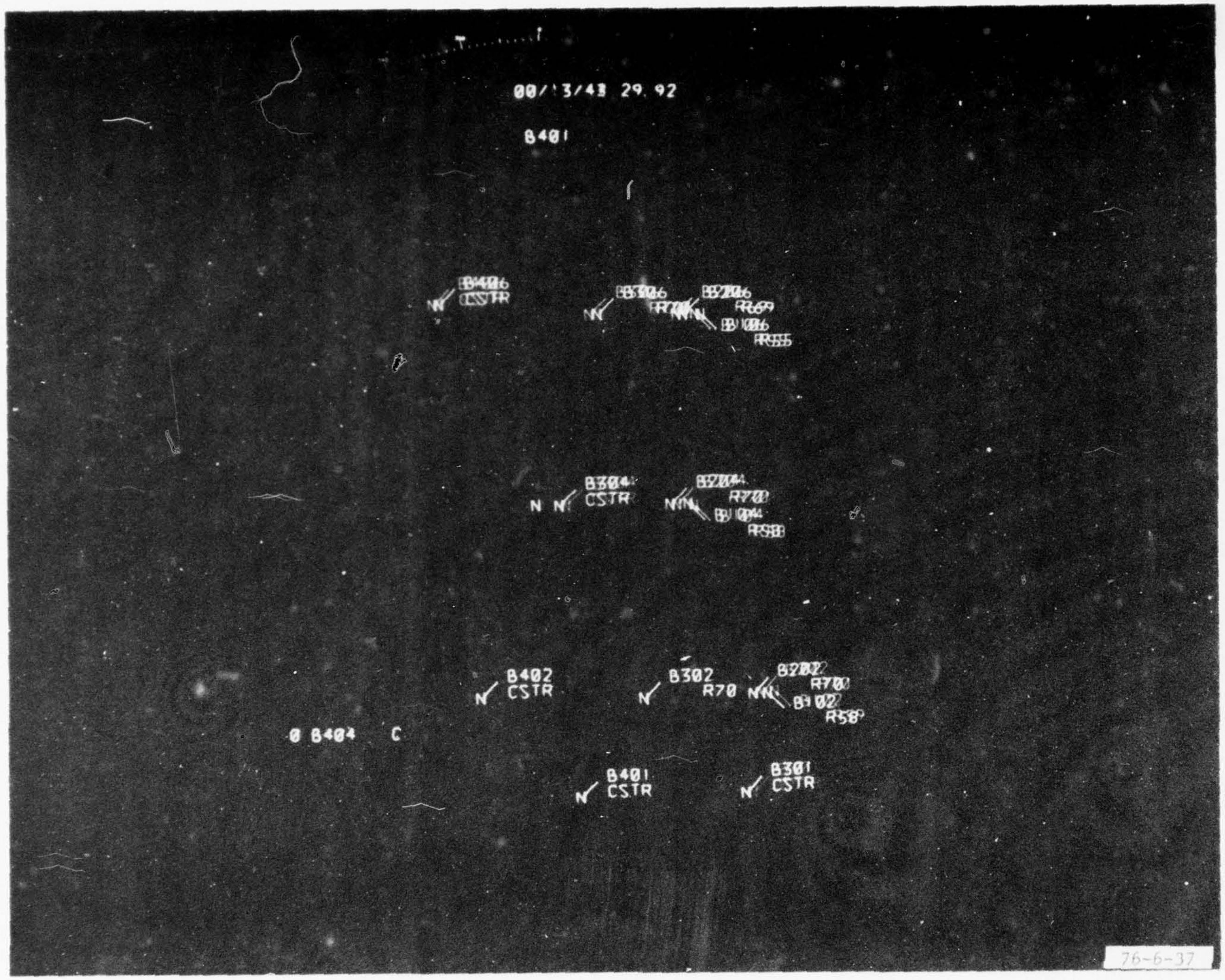


FIGURE 37. RADAR DISPLAY PHOTO--RBS SCENARIO 025 SHOWING TRACK COAST COMMENCING AT 700 KNOTS

CONCLUSIONS

AIRCRAFT POSITION ACCURACY.

1. The accuracy* to which ARTS III** can report aircraft positions is ± 0.10 nmi in range and $\pm 0.87°$ in azimuth. Range-error variability is primarily a function of the 0.0625-nmi range resolution of the ARTS III itself. There is no correlation between the magnitude of range and azimuth reported errors and the distance of the target from the radar.

There is no practical difference in the ARTS III** position-reporting accuracy between beacon-only and radar-reinforced beacon targets.

There is no practical difference in ARTS III** position-reporting accuracy between radar-only and radar-reinforced beacon targets.

2. The accuracy* to which ARTS III** can predict successive aircraft positions (track) is ± 0.40 nmi in range and $\pm 1.04°$ in azimuth when the aircraft is in tangential flight. The corresponding values for straight flight are ± 0.17 nmi and $\pm 0.51°$.

The accuracy of the target reports are greater than those of the predicted positions for both straight and tangential flight.

3. The accuracy* to which the ARTS III** radar display can display aircraft position is ± 0.12 nmi in range and $\pm 1.04°$ in azimuth. For a calibrated display, this error variability is less than that generated in trying to read position from the radar displays.

4. The overall accuracy* to which ARTS III** can report and display aircraft positions is ± 0.16 nmi in range and $\pm 1.43°$ in azimuth. Again, these errors are less than those generated in trying to read position from the radar displays.

AIRCRAFT SEPARATION ACCURACY.

The accuracy* to which ARTS III** can report aircraft separations is ± 0.163 nmi. Separation error variability is primarily a function of the 0.0625-nmi range and 0.088° azimuth resolution of the ARTS III.

AIRCRAFT RESOLUTION ABILITY.

The ARTS III target resolution is estimated to be 2.0 nmi when targets are separated in range from the radar and 6° when separated in azimuth. These are 90-percent estimates, i.e., 90 percent of the time, when both targets are separated in range or azimuth by at least the amounts indicated above, both aircraft will be properly identified.

MODE C ALTITUDE REPORTING ACCURACY.

The accuracy* to which ARTS III** can report mode C altitudes is ±96 feet, given a standard atmosphere. Altitude error variability is primarily a function of the 100 feet altitude resolution of the aircraft transponder.

DISPLAYED GROUNDSPEED ACCURACY.

The accuracy* to which ARTS III** can predict groundspeed is ±32 knots. Speed is displayed to the nearest 10 knots.

DETECTING AND TRACKING LIMITATIONS.

Simulation testing reveals that a beacon reply occupies a radar area of dimensions 2 nmi in range and one ATCBI antenna beamwidth (nominally 4.5°) in azimuth. The azimuth beamwidth, in linear dimensions, varies directly with range; increasing from 0.2 nmi at 2.5-nmi range, to 2 nmi at the 25-nmi range. Whenever two beacon targets are within this common area, mode A and/or mode C crosstalk may occur, resulting in garbled codes and/or altitudes, and making track swaps possible. Whenever three beacon replies emanate from this common area, track swaps are virtually certain to occur. The airspace requirements of a radar-only target are defined primarily by the ASR antenna beamwidth (nominally 1.5°). Targets as close as 0.2 nmi can be tracked if their azimuth separation is at least one beamwidth. Whenever two or more radar-only targets possess less than this separation, track validity is lost.

Track retention during turning is primarily dependent on the maintenance of unity round reliability, a situation not normally achievable in the live environment. In simulation, where unity round reliabilty was maintained, track retention was shown to be almost independent of turn rate under normal maneuvering conditions; i.e., as long as flightpath accelerations do not result in displacements that exceed tracking bin dimensions. In live testing, where round reliability in turns regularly drops to 0.8 to 0.9, displayed track position and airspeed errors are greatly magnified. Controller entries to reposition tracks are often required to insure track retention.

The ARTS III RBTL performance with nonbeacon-equipped aircraft was limited by the lower round reliability (observed to average approximately 0.5); this was attributed to variations in the signal-to-noise ratio of the radar return as range, track, aircraft attitude, and meteorological conditions changed. The detection probability of beacon-equipped aircraft similarly was only slightly enhanced by radar reinforcement.

* 99.9 percent of the errors can be expected to fall within the stated limits about the mean error with a confidence of 90 percent.

** ARTS III (RBTL)/ATCBI-3

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7. Busch, Allen C. and Bradbury, Paul W., DAIR System Radar Target Relationships, Federal Aviation Administration, FAA-RD-74-155, October 1974.

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11. Mission Reports, Activity 142-177-040, Terminal ATC Digital Display System Error, ARTS III, Federal Aviation Administration, ANA-140 NAFEC, 20 May 1974--17 January 1975.

12. Duncan, A. J., Quality Control and Industrial Statistics, Richard D. Irwin, Inc., 1965.

APPENDIX A

NAFEC TEST SUPPORT FACILITIES

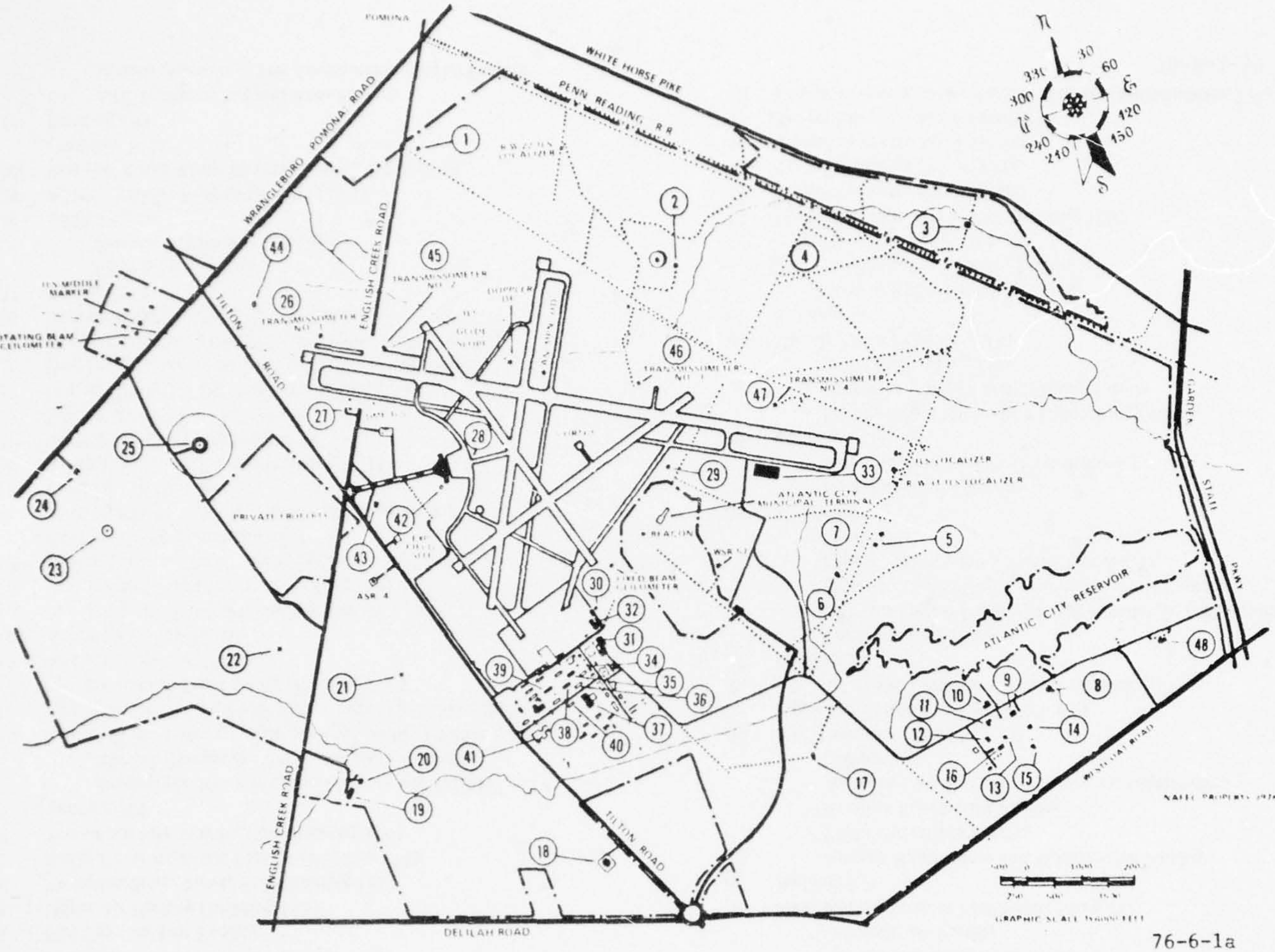
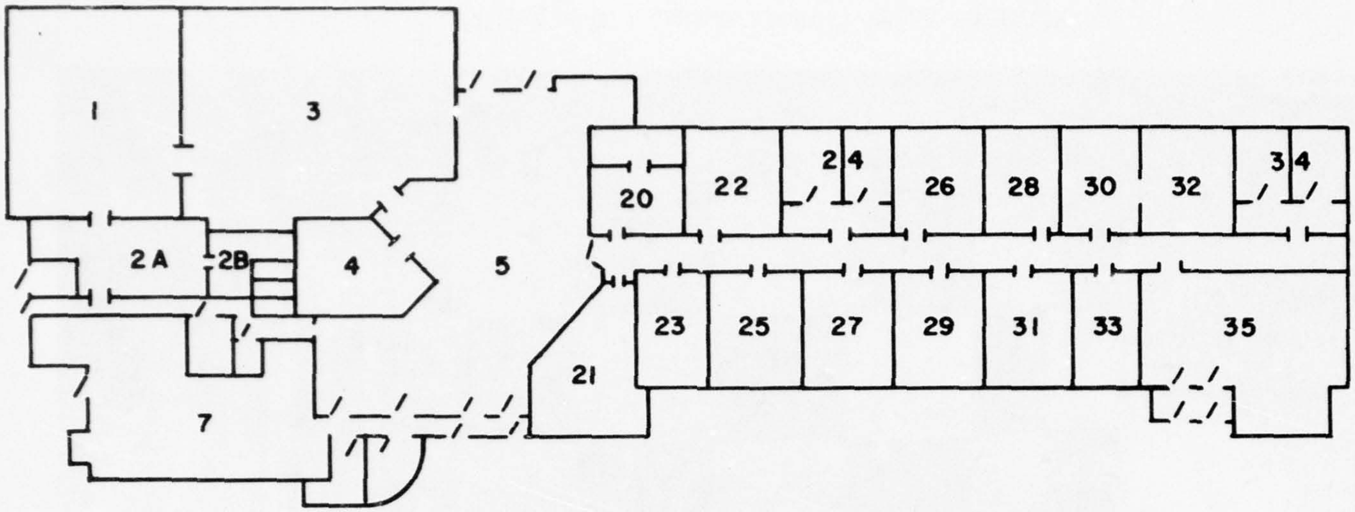


FIGURE A-1a. NAFEC FACILITIES MAP

1 Phototheodolite Tower P36 (Building 187)
2 Antenna Test Range (Building 192)
3 Phototheodolite Tower P8 (Building 184)
4 Fire Fighting Test Facility
5 Upper Air Facility (Building 193)
6 Phototheodolite Tower P13 (Building 185)
7 Range Control Central Facility (Building 174)
8 Five-Foot Fire Test Facility (Building 204)
9 Building 205
  Buildup and Instrumentation Laboratory Facility
  Aircraft Component Test Laboratory Facility
10 Standards and Calibration Laboratory Facility (Building 201)
11 Equipment Safety Test Laboratory Facility (Building 203)
12 Air Gun Impact Test Facility (Building 202)
13 Aircraft Drop Test Facility
14 Aircraft Test Pad Facility
15 Fire Test Cell and Blower Facility (Building 211)
16 Catapult and Track Facility (Building 214)
17 Central Communications Facility, Transmitter Site and Patching Facility (Building 70)
18 ASR-5/ATCBI-3 Radar Facility (Building 162)
19 Building 170 (Storage)
20 Audio Laboratory Facility (Building 171)
21 VORTAC Facility (Building 196)
22 EAIR Facility (Building 223)
23 Doppler VOR (DVOR) Facility (Building 188)
24 Peripheral Communications Facility (Building 176)
25 Doppler VORTAC (DVORTAC) Facility (Building 169)
26 Experimental Runway Lighting Facility
27 Building 161
  Glide Slope Facility
  Runway Lighting Control Site
28 TAIR Facility
29 ASDE-2 Radar Facility (Building 180)
30 Runway Visual Range (RVR) Terminal Equipment (Building 137)
31 Building 149
  ATC Technical Support Area Facility
  System Integration Test Environment (SITE) Facility
  Test Control Facility (NAFEC Radar)
  Test Control Coordination Facility
  No. 300 Switching System Facility
  Computation Facility
32 Photographic Services Facility (Building 48)
33 Building 301
  Aircraft Maintenance and Modification Facility
  Flight Operations Facility
  Aviation Engineering Facility
  Airborne Data Facility (Airborne Instrumentation Laboratory)
34 ATC Laboratory (Building 55)
35 Flight Simulation Facility (Building 5)
36 ATC and Flight Simulation Facilities (Building 7)
37 Building 19
  Computation Facility
  ATC Simulation Facility, which includes an Alpha-numeric Situation Digital Display Facility, Special Purpose Digital Facility, and a Radar Digitizer for Simulation.
38 Building 6
  Data Preparation Facility
  Airborne Data Facility (Engineering)
39 Building 2
  Standards and Calibration Laboratory Facility
  Engineering Design and Drafting Facility
  Printed Circuit Facility
40 Visuals Facility (Building 18)
41 Building 14
  ASR-2 Radar Facility
  Mechanical Laboratory Facility
42 ATC Tower (Building 150)
43 Phototheodolite Tower P29 (Building 186)
44 Transmissometer No. 1 System
45 Transmissometer No. 2 System
46 Transmissometer No. 3 System
47 Transmissometer No. 4 System
48 Central Communication Facility Receiver Site (Building 224)

76-6-A-1b

FIGURE A-1b. MAP LEGEND



ROOM NO.	FUNCTION
1	ARTS III DISPLAY LAB (1600 SQ. FT.)
2A	COMMUNICATIONS EQUIPMENT ROOM (845 SQ. FT.)
2B	SIMULATION PILOT'S DISPLAY ROOM (255 SQ. FT.)
3	ELECTRONIC EQUIPMENT ROOM (2400 SQ. FT.)
4	ARTS II DISPLAY LAB (500 SQ. FT.)
5	GENERAL AVIATION & LOBBY
7	BUILDING UTILITIES
20	SPARE PARTS AND STAGING AREA (600 SQ. FT.)
21	SUPPORT SYSTEM (600 SQ. FT.)
23	PROPOSED TECHNICAL LIBRARY
26	CONFERENCE ROOM
35	READY ROOM (1100 SQ. FT.)
BALANCE	ADMINISTRATIVE SPACES (6100 SQ. FT.)

76-6-A-2

FIGURE A-2. PLAN VIEW OF THE TERMINAL AUTOMATION TEST FACILITY

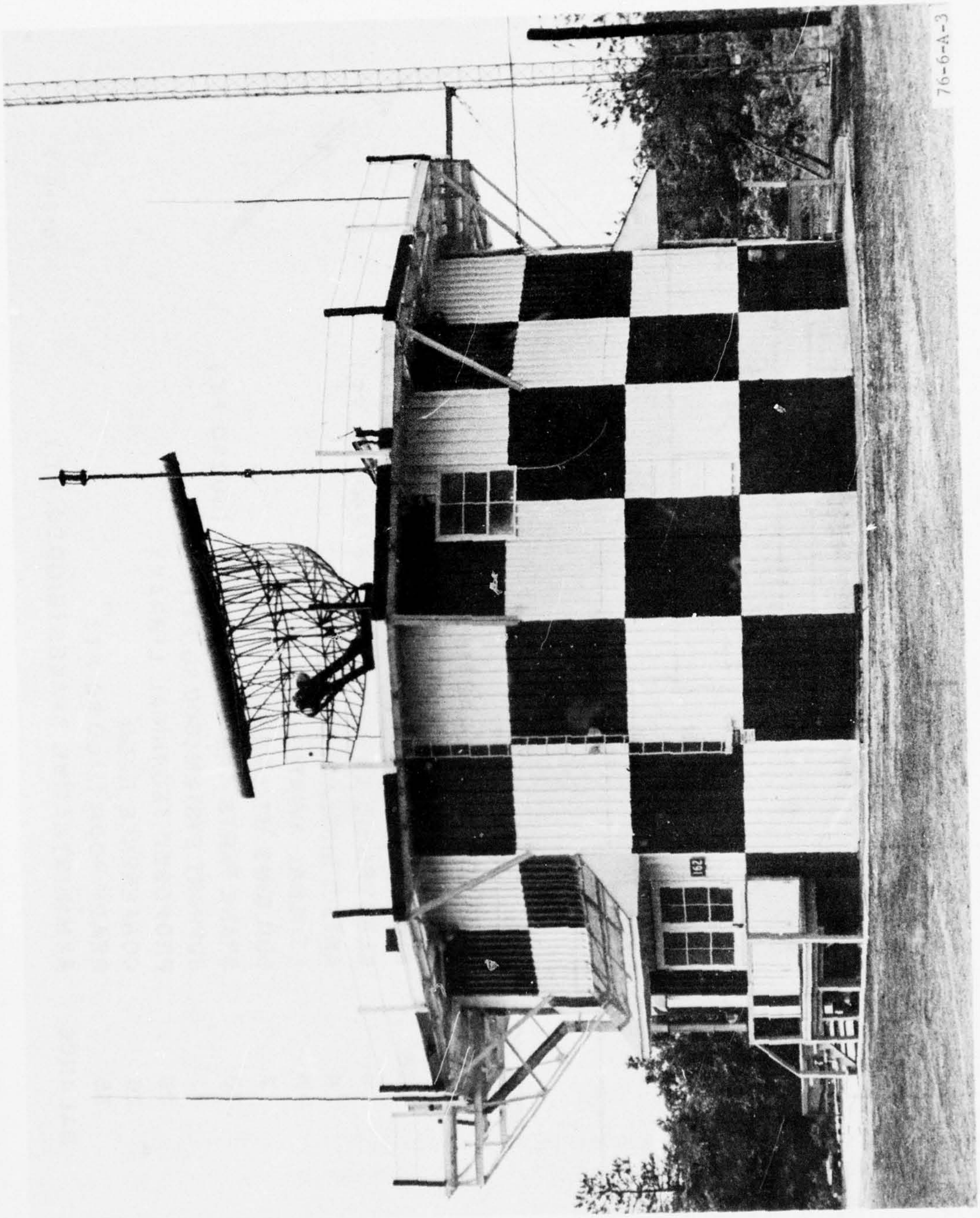
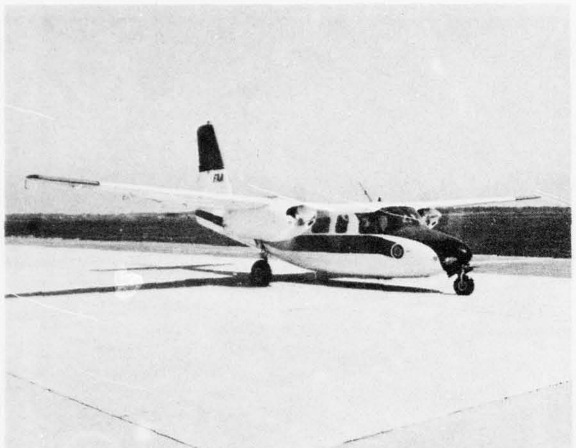


FIGURE A-3. ASR-5 ATCBI-3 RADAR FACILITY



N477 AERO-COMMANDER AC680E

N247 CONVAIR UT29C

N376 GRUMMAN G159

N464 DOUGLAS DC7

FIGURE A-4. TYPICAL NAFEC TEST AIRCRAFT

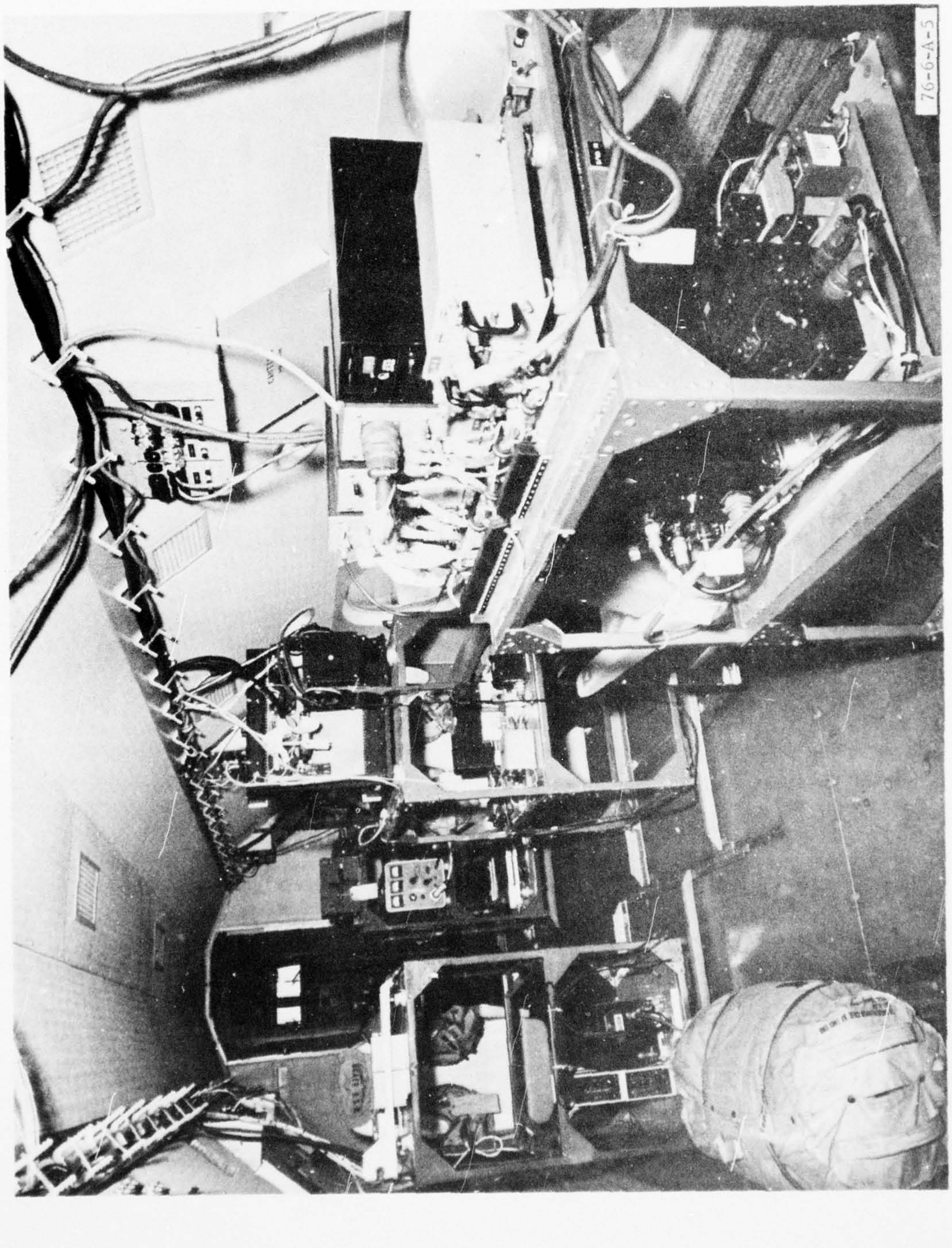


FIGURE A-5. INSTRUMENTATION, TYPICAL NAFEC TEST AIRCRAFT

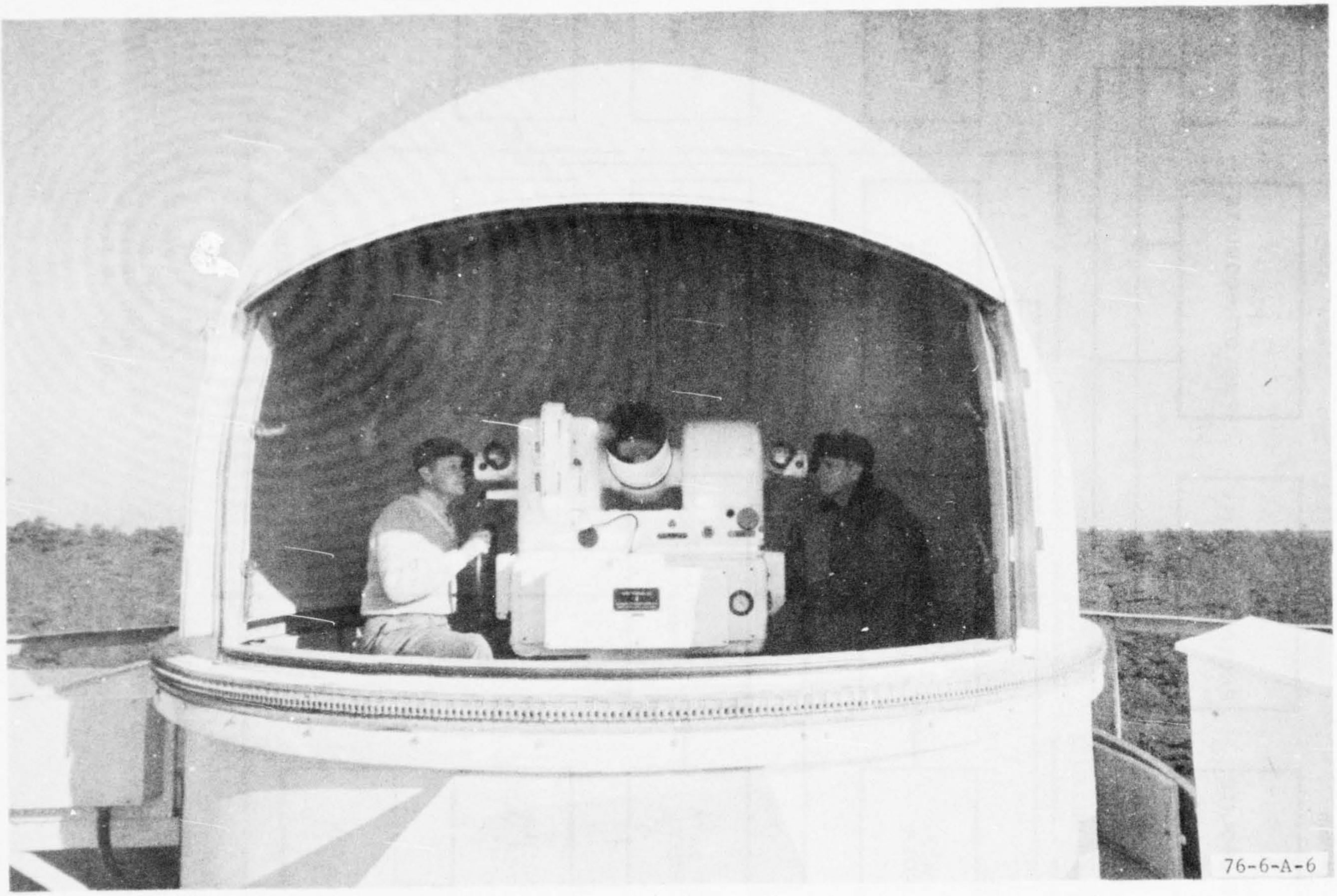


FIGURE A-6. PHOTOTHEODOLITE INSTRUMENT

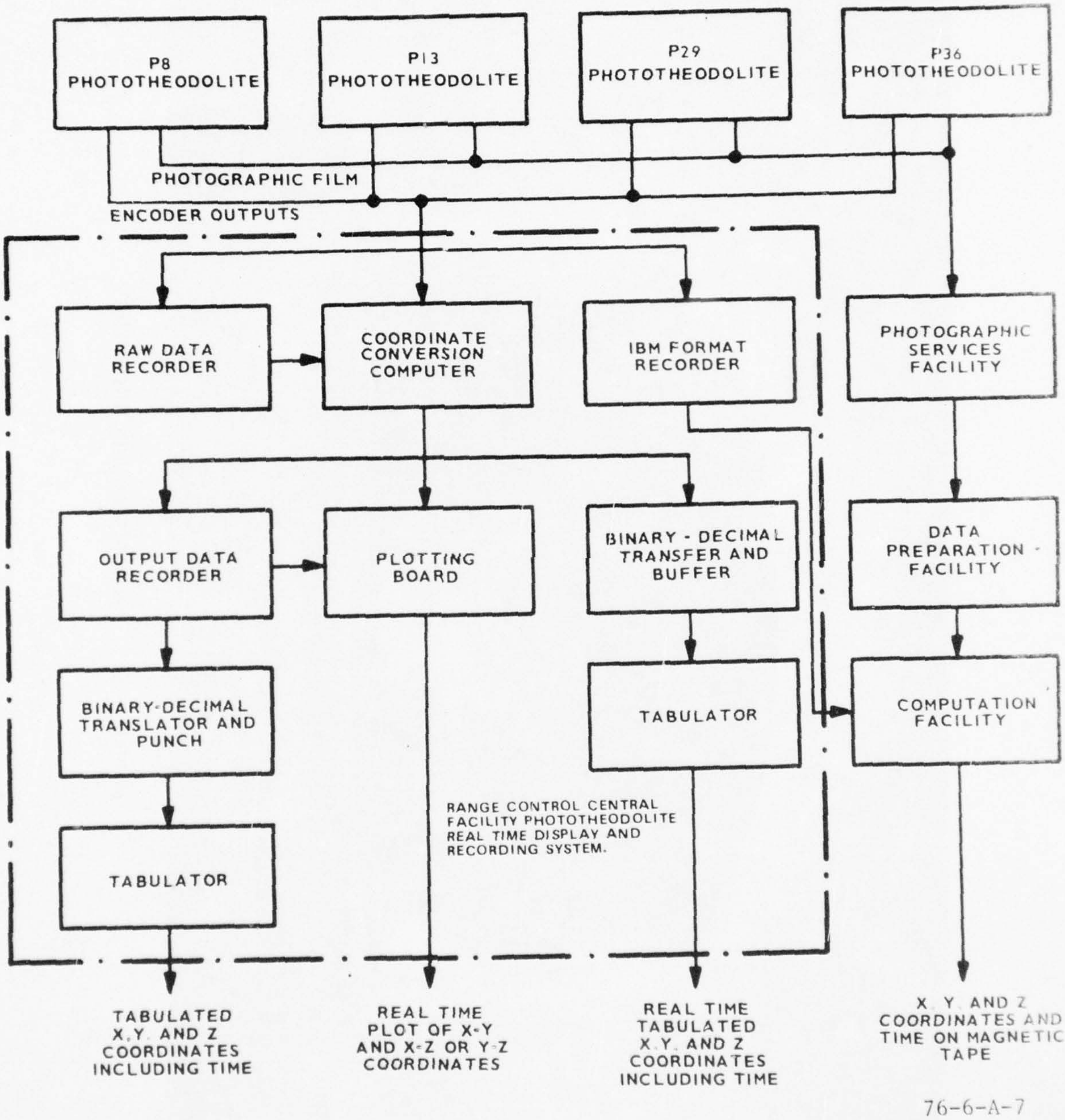


FIGURE A-7 PHOTOTHEODOLITE DATA FLOW DIAGRAM

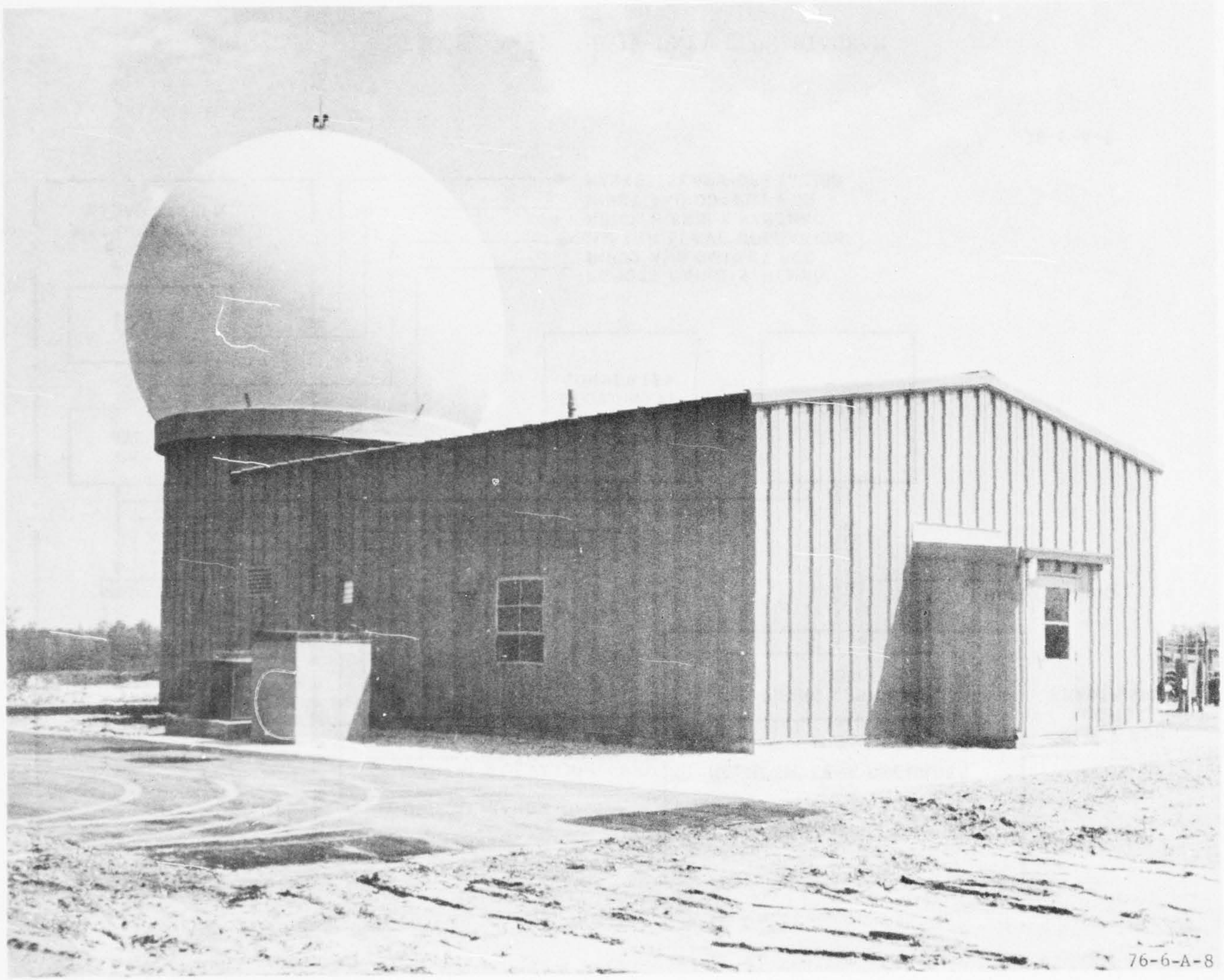
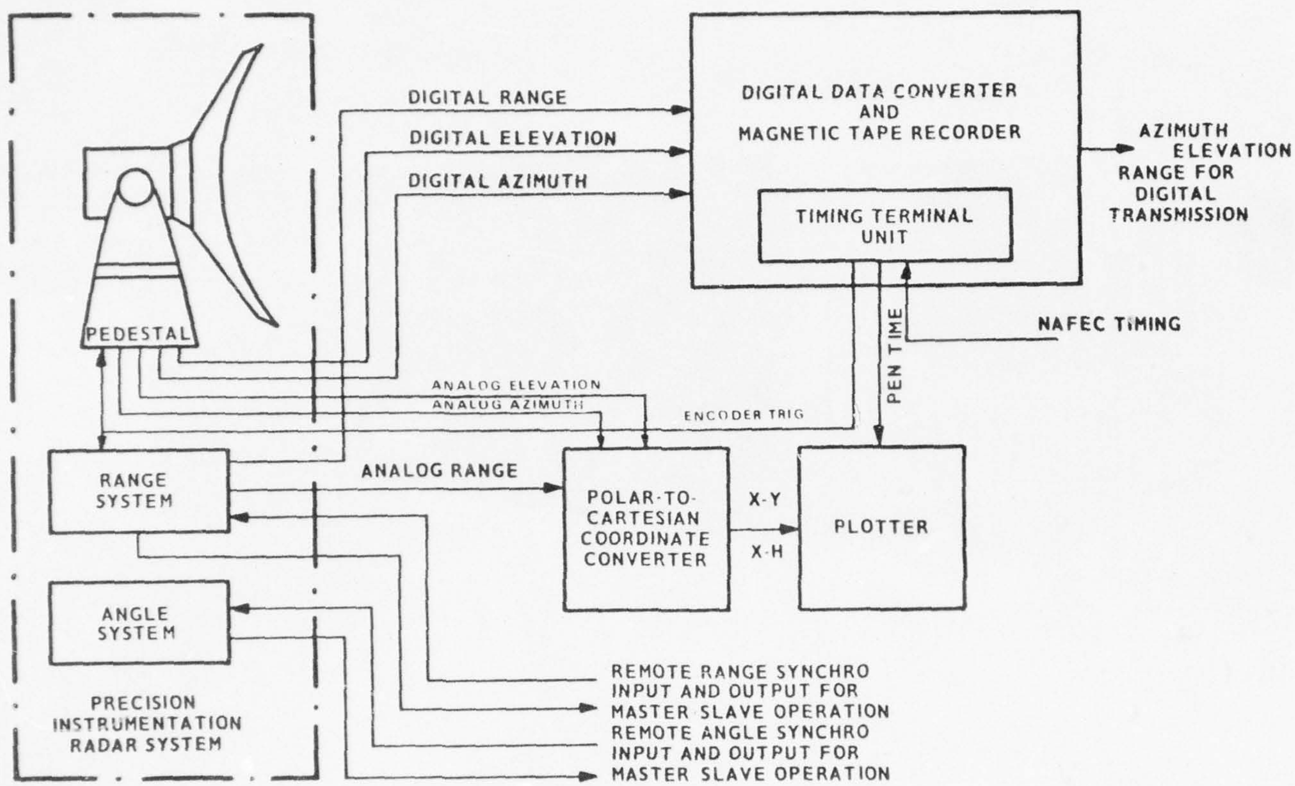


FIGURE A-8. EXTENDED AREA INSTRUMENTATION RADAR (EAIR)



76-6-A-9

FIGURE A-9. FAIR DATA FLOW DIAGRAM

FIGURE A-10. RANGE CONTROL CENTRAL FACILITY

AD-A034 494 NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER ATL--ETC F/G 17/7
AIRSPACE CONFIGURATION AND SEPARATION EVALUATION--CONFIGURATION--ETC(U)
NOV 76 H T MORGAN, A R MOSS

UNCLASSIFIED FAA-NA-76-6 FAA-RD-76-178 NL

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A034494

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DATE
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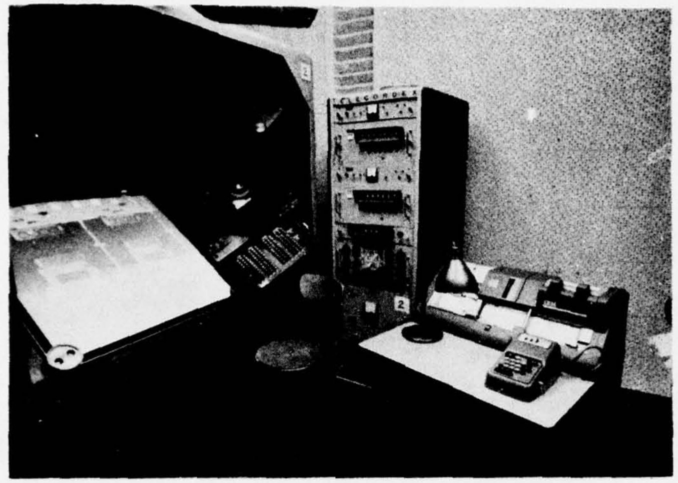
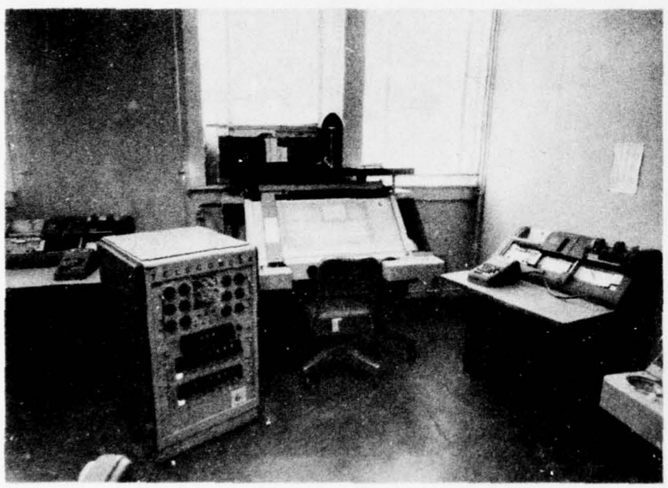
2-77





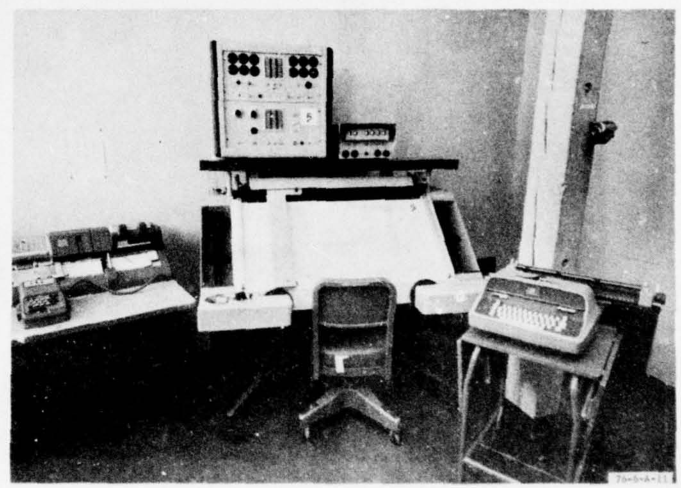
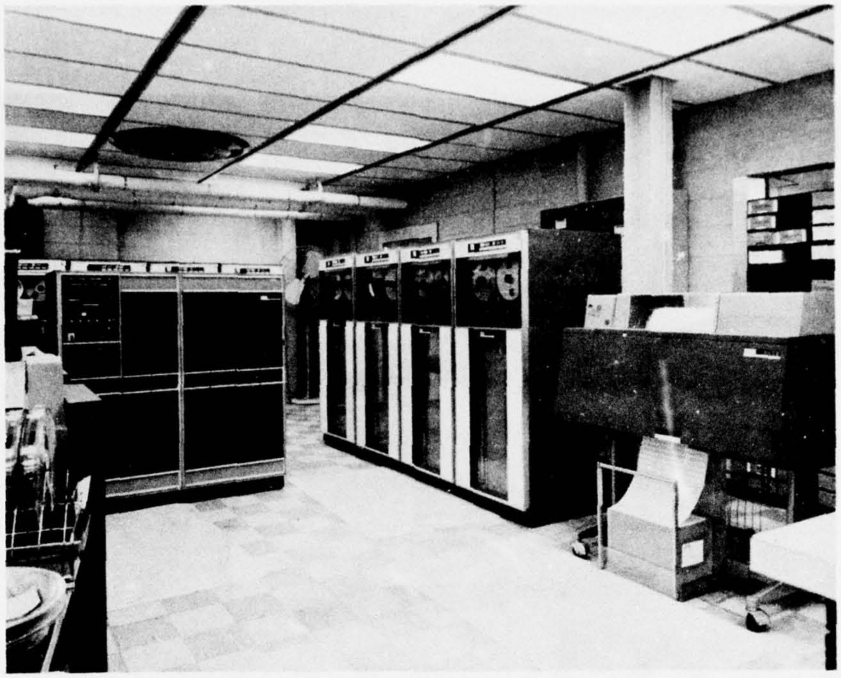
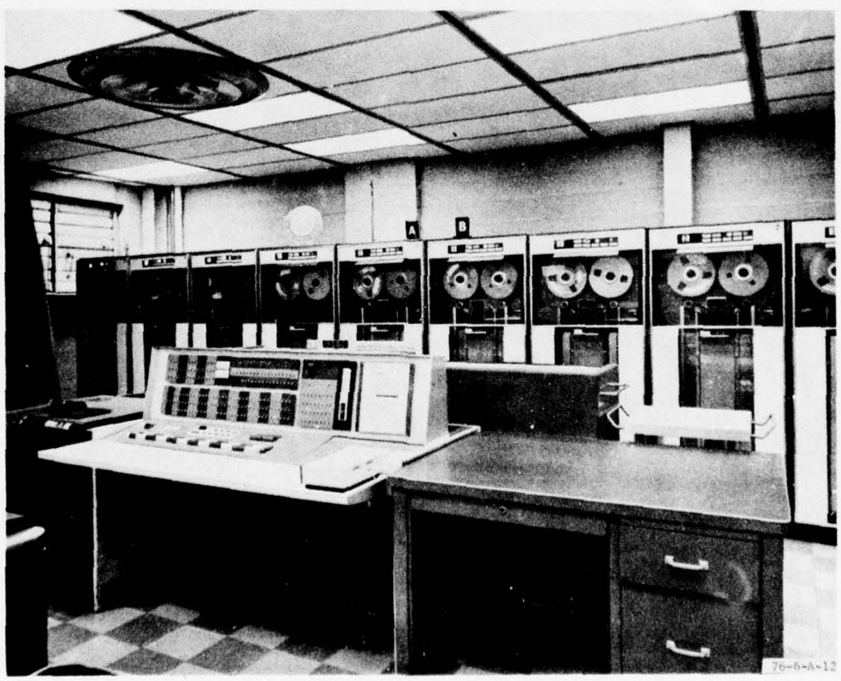


FIGURE A-11. DATA PREPARATION FACILITY



a. IBM 1401 DATA PROCESSING SYSTEM



b. IBM 7090 DATA PROCESSING SYSTEM

FIGURE A-12. DATA PROCESSING FACILITY

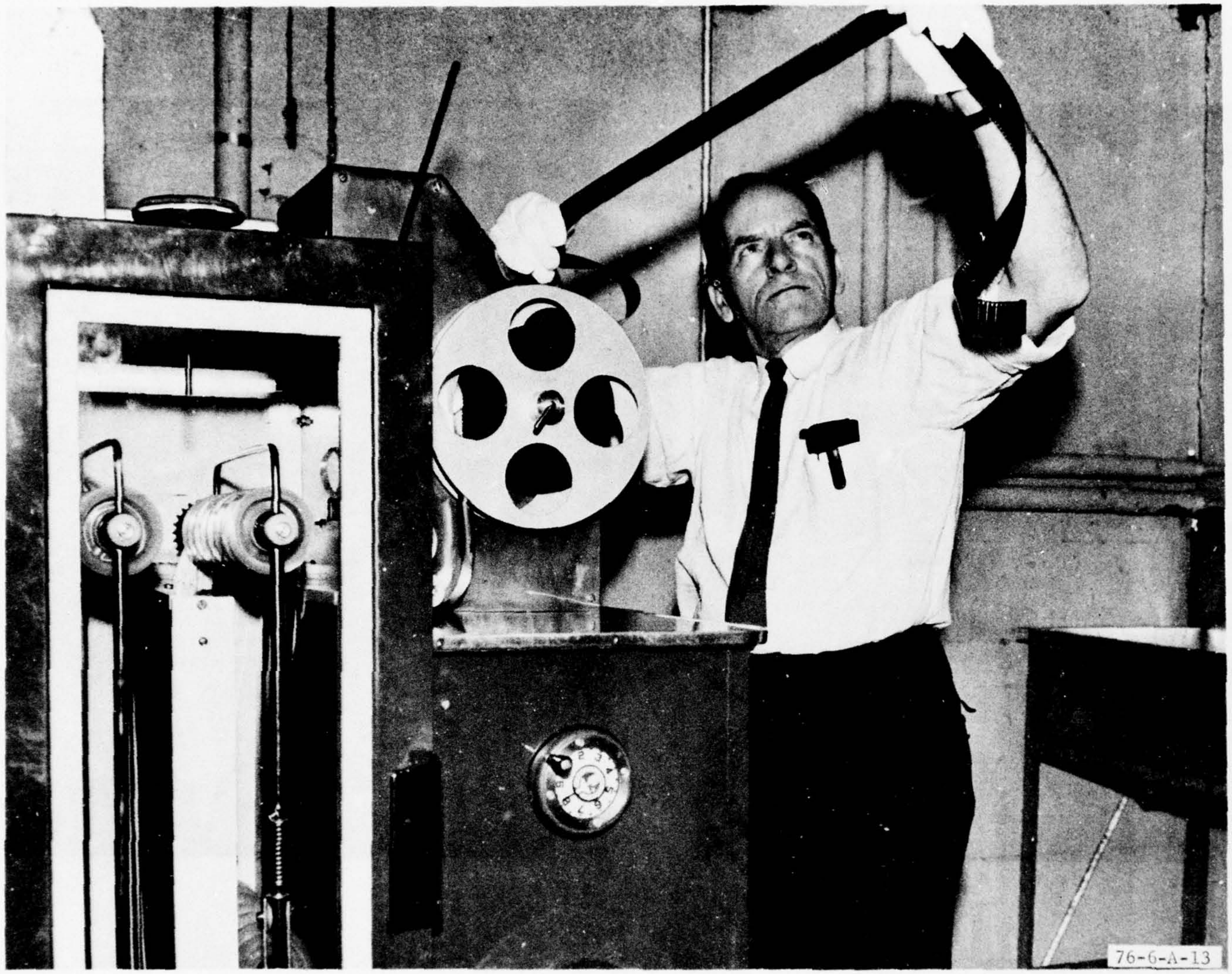


FIGURE A-13. PHOTOGRAPHIC INSTRUMENTATION PROCESSING AREA

APPENDIX B

DATA REDUCTION SOFTWARE

APPENDIX B1

UNIVAC EXTRACTOR TAPE PROGRAM

Figure B-1 shows a sample of the printout produced by this ARTS III program. The program prints out the target reported and predicted positions that occur within each sector of azimuth. There are 32 sectors per scan; hence, each sector comprises 11.25° or 128 azimuth change pulses (ACP's). On the extreme left of the printout is the sector time. Looking at the line marked (a) in figure B-1, it will be noted that this sector began at 10:35:57.773 hours. On the line below, marked "1 TARGET RPT", it will be noted that three beacon target reports occurred during this sector. Looking at the first, or leftmost target report, the character group 1768W will be noted to the extreme left. The 1768 is the azimuth of the target in ACP's. This corresponds to a bearing of 155.39°. The symbol "W" is one of two symbols which indicate target strength. This is a function of the number of hits in the beacon sliding window, which is used for the determination and positioning of the beacon target. The symbols are "W" for weak targets and "S" for strong targets. A weak target is indicated by up to seven or eight hits in the sliding window (depending on mode interlace); a strong target report is indicated by eight, nine, or more hits in the sliding window.

The next group of characters reading to the right is 03.88. This is the range of the target in nautical miles. Following this is the group of characters 0176-3. The 0176 is the mode 3/A beacon identity (ID) code. The "3" is the mode 3/A validity figure. The validity figure is a figure of merit concerning the accuracy of the received beacon ID code (0176). The number "3" is the highest possible value for this mode 3/A validity figure.

Following the mode 3/A character group, the characters "031-2" will be noted. The "031" stands for the mode C beacon altitude in hundreds of feet (i.e., 3,100 feet), and the "2" after it is the mode C validity figure, which, like the mode 3/A validity figure, is a figure of merit concerning the accuracy of the received beacon mode C altitude code. As in the case of the mode 3/A validity figure, the number "3" is the highest possible value for the mode C validity figure.

The final character in the target report is a numeral ranging from 0 to 7. This is the radar quality (RQ) number, which is an indication of the number of hits in the radar sliding window. For the target report under discussion, it will be noted that this character is a "0". This indicates no radar returns at all from the target; hence, this is a beacon-only target. An RQ indication of 1 is the weakest radar target, indicating eight or less hits in the radar sliding window. An RQ indication of 7 is the strongest radar target, indicating 19 or more hits in the radar sliding window.

```
10:35:55.875 1SECTOR TIME
             1TARGET RPT         0123S  33.44 1230-3 311-3 0 0395S  55.01 0401-3 370-3 3 0199S  34.09 2457-3 410-3 0
                                 0219S  54.13 1200-3 000-0 0
10:35:55.331 1SECTOR TIME
             1TARGET RPT         0259S  18.19 1200-3 000-0 0 0247S  48.63 2557-3 167-3 6 0257S  55.19 0603-3 069-3 0
                                 0333S  21.19 1706-3 064-3 7
10:35:56.164 1SECTOR TIME
             1TARGET RPT         0392S  36.01 1200-3 000-0 0
10:35:56.312 1SECTOR TIME
             1TARGET RPT         0483S  02.81 1203-3 386-3 0 0505S  13.38 1203-3 031-3 5
10:35:56.468 1SECTOR TIME
             1TARGET RPT         0625S  41.94 4705-3 138-3 7 0629S  55.06 3255-3 041-3 6 3662   21.17 RADAR        3
                                 0689S  32.88 1200-3 000-0 0
10:35:56.601 1SECTOR TIME
             1TARGET RPT         0786S  01.13 0202-3 000-0 0 0794S  46.31 1335-3 200-3 2
10:35:56.765 1SECTOR TIME
             1TARGET RPT         0940S  24.31 1177-3 117-3 0
10:35:56.951  #1312        AUTO INITIATE
10:35:56.898 1SECTOR TIME
             1TARGET RPT         1019   20.06 RADAR        1
10:35:57.195 1SECTOR TIME
             1TARGET RPT         1322S  42.63 4000-3 374-3 0
10:35:57.335 1SECTOR TIME
             1TARGET RPT         1385S  12.75 1134-3 380-3 0 1427S  48.38 4001-3 187-3 3
10:35:57.632 1SECTOR TIME
             1TARGET RPT         1688S  09.56 1200-3 300-0 7
A 10:35:57.773 1SECTOR TIME
             1TARGET RPT         1768W  03.88 3176-3 031-2 0 1829S  03.25 0177-3 335-3 3 1836S  03.88 6176-1 303-1 2
B 10:35:58.076 1SECTOR TIME
             1TARGET RPT         2081   57.9  RADAR        7 2080   59.29 RADAR        7 2340S  54.06 0000-3 309-0 0
C 10:35:58.474  N376      R C31 0176 0176 1806 C.,63  C1.32 -03.35 F47 VEL 22 U3.25 03.94 1750 1862 02.94 04.25 1694 1518
               3000323312 1637133500 7523330522 7143304200 0333737557 3304700003 0017696390 0333909000 4017630061
               4432400C77 0004002042 000000000C 0010L00000
10:35:58.367 1SECTOR TIME
             1TARGET RPT         2319S  29.31 2504-3 311-3 7 2377S  17.50 4600-3 000-0 0
10:35:58.507 1SECTOR TIME
             1TARGET RPT         2471   16.69 RADAR        1 2500S  37.88 3644-3 230-3 2
10:35:58.664 1SECTOR TIME
             1TARGET RPT         2612S  25.25 2251-3 330-3 0 2625S  42.94 1200-3 067-3 0
10:35:58.804 1SECTOR TIME
             1TARGET RPT         2682   22.75 RADAR        2 2688S  31.63 2621-3 170-3 5 2734S  34.31 2542-3 260-3 0
                                 2752S  35.38 1200-3 300-0 0
10:35:58.968 1SECTOR TIME
             1TARGET RPT         2785S  22.69 2274-3 134-3 0 2835S  34.50 1203-3 065-3 3 2892S  55.13 1200-3 044-3 0
10:35:59.189  #1313        AUTO INITIATE
10:35:59.101 1SECTOR TIME
             1TARGET RPT         2978   06.75 RADAR        7 3012W  57.19 1200-3 000-0 0
10:35:59.242 1SECTOR TIME
             1TARGET RPT         3137S  78.00 2214-3 350-3 3 3145W  55.50 1200-3 000-0 0
10:35:59.398 1SECTOR TIME
             1TARGET RPT         3174S  51.25 1200-3 036-3 0 3205S  57.81 1200-3 042-3 0 3227S  45.69 3313-3 150-3 0
10:35:59.539 1SECTOR TIME
             1TARGET RPT         3376S  50.06 3406-3 169-3 7 3406S  20.94 2560-3 282-3 1 3410S  23.94 1200-3 000-0 7
10:35:59.679 1SECTOR TIME
             1TARGET RPT         3460S  27.00 2571-3 058-3 7 3520S  32.50 2145-3 283-3 7
10:35:59.835 1SECTOR TIME
             1TARGET RPT         3594S  42.88 0567-3 022-3 0 3605S  15.75 1200-3 000-0 7 3624S  28.00 0120-3 000-0 0
                                 3635S  55.98 2516-3 150-3 0
10:35:59.976 1SECTOR TIME
             1TARGET RPT         3687S  43.94 3321-3 142-3 0 3745W  21.88 1203-3 340-3 7 3710S  27.88 1200-3 300-3 3
                                 3751S  31.16 2735-3 127-3 0 3725S  49.81 7463-3 734-3 3 3754S  35.19 1200-3 072-3 0
                                 3751   31.69 RADAR        2 3776S  36.66 2744-3 026-3 2
```

76-6-B-1

FIGURE B-1 UNIVAC EXTRACTOR TAPE DATA REDUCTION PROGRAM LISTING

The second target report in this sector is a strong target at 1,820 ACP's in azimuth, 3.25 nmi in range, with beacon mode 3/A ID code of 0177, mode 3/A validity of 3, at an altitude of 3,500 feet with a mode C validity of 3, and a radar quality of 4. The third target report in the sector is a strong target at 1,806 ACP's azimuth, 3.88 nmi in range, with beacon ID of 6176 and at 0 feet altitude. It will be noted that the validity numbers for both beacon ID and altitude are each only 1, indicating poor accuracy of beacon ID and altitude decodings. Since this target is at the same range and almost the same azimuth as the first target report, and has a similar beacon ID code (6176 versus 0176), the third target report may represent a misdecoding or garble of the 0176 code.

Looking at line b, we see that for the sector beginning at 10:35:58.070, there were three target reports. The first two groups of characters are similar to those of the line above, except there is no symbol for beacon strength in the first character group. The first target report is seen to be at 2,081 ACP's in azimuth and 57.88 nmi in range, while the second target is at an azimuth of 2,080 ACP's and a range of 58.25 nmi. The third character group, which had previously indicated the mode 3/A beacon ID code, now indicates "RADAR". This means that the target report consisted of primary radar returns only; there were no beacon returns at all from the target. The lone digit on the right, as before, represents the radar quality, or RQ, which, for both radar-only targets in this sector, is a 7, or highest quality radar return. The right-most target in line b is a strong beacon-only target at 2,080 ACP's azimuth, 59.06 nmi range, with beacon ID code of 0000 with mode 3/A validity of 3. The fourth or altitude group for this target is 0000-0, which, since the mode C validity is 0, indicates no mode C altitude transmission from the transponder. Line c shows a predicted target position occurring at 10:35:58.474 hours. This is a predicted position on aircraft N376. The character "R" to the right of the aircraft ID group indicates that the prediction was based upon a radar or beacon target report, rather than an extrapolated position or "coast" mode, for which the symbols "CST" would be displayed. The next group of characters, 031, indicates the aircraft altitude in hundreds of feet--i.e., 3,100 feet. Following this are two identical groups of characters, 0176, indicating the mode 3/A beacon identity code. The next group of characters, 1806, is the azimuth of the track in ACP's. The next three groups of characters represent the range (3.63 nmi), and the x and y components of the range. The next group of characters (F47) represents the track firmness, in octal notation. The track firmness is a figure of merit concerning the quality of the track. The numeral "47" in octal notation corresponds to 39 in decimal notation, which is the highest value of track firmness. The next character group "VEL 22" indicates a track velocity of 220 knots.

APPENDIX B2

ARTS III RBTL UNPACK PROGRAM

Figure B-2 shows a sample of the printout produced by this program. The selected beacon ID's in this case were 0176 and 0177. Lines a and c correspond to the reported and predicted target position messages shown in lines a and c, respectively, of the extractor tape listing sample (figure B-1). It will be seen that for the two target reports marked "a"; the time, mode 3/A beacon ID's, mode C altitudes, and RQ's are the same as those shown for the corresponding target reports on line a of figure B-1. The azimuth readings have been changed from ACP's to degrees, and the validity and beacon strength indications are shown as the three right-most digits under the column heading "REFACW FLAGS". The most significant digit in this group under the "A" of REFACW, is the mode 3/A validity number, which, for both targets, is 3. The second digit, under the "C" of REFACW, is the mode C validity number. This is 2 for the 0176 target and 3 for the 0177 target, corresponding to what was displayed in figure B-1. Finally, the W and S beacon strength indication characters of figure B-1 have been given the numerical codings of 0 and 1, respectively, and are so shown under the "W" of REFACW.

In the case of the predicted position shown in line c, it will again be noted that the items correspond to the values shown in line c of figure B-1, except that the azimuth is displayed in degrees, and track firmness is indicated in decimal notation rather than octal. The aircraft groundspeed in knots, together with its x and y components, are also provided.

RBTL DATA RUN 1 — UNPACK J-194 RBTL ARTS III 06/04/75

	TIME HR	MN	SEC	TARGET 3/A	RGE NMI	AZIM DEG	ALT CFT	RQ	REFACW FLAGS	TRACK ACID	FM	3/A	RGE NMI	AZIM DEG	ALT CFT	ALT STAT	YSP KNOTS	XSP KNOTS	GR SP KNOTS	ACCVVRSC CC ACTI	/
	10	35	48.41	176	3.06	160.84	C	7	000301												
	10	35	48.41	177	2.88	162.16	35	0	000331												
	10	35	53.09	176	3.56	158.99	31	1	000331												
	10	35	53.09	177	3.06	160.93	29	0	000331												
	10	35	53.77							N376	37	176	3.25	159.79	C	000	-165.23	116.02	201.90	01130000	6
A	10	35	57.77	176	3.88	155.39	31	0	000320												
A	10	35	57.77	177	3.25	159.96	35	4	000331												
C	10	35	58.47							N376	39	176	3.63	158.73	31	000	-179.30	119.53	215.49	00133000	6
	10	36	2.48	177	3.50	158.99	35	0	000331												
	10	36	3.04							N376	39	176	4.00	155.04	31	000	-161.72	168.75	233.73	00132000	6
	10	36	7.16	177	3.69	158.47	35	4	000331												
	10	36	11.84	177	3.88	158.20	35	6	000331												
	10	36	16.54	176	5.19	155.57	31	7	000331												
	10	36	16.54	177	4.13	157.24	35	2	000331												
	10	36	20.92	176	5.50	134.47	31	0	000331												
	10	36	21.22	176	5.56	155.04	31	4	000331												
	10	36	21.22	177	4.31	157.06	35	6	000331												
	10	36	21.71							N376	39	176	5.50	155.30	31	000	-225.00	140.63	265.33	00133000	6
	10	36	25.91	177	4.50	157.06	35	7	000331												
	10	36	25.91	176	5.88	154.86	31	4	000131												
	10	36	26.42							N377	39	177	4.50	156.53	35	000	-133.59	87.89	159.91	00133100	6
	10	36	26.42							N376	39	176	5.88	154.78	31	000	-225.00	147.66	269.12	00133000	6
	10	36	30.59	176	6.25	154.16	31	7	000331												
	10	36	30.59	177	4.69	156.27	35	3	000331												
	10	36	31.12							N377	39	177	4.69	156.62	35	000	-137.11	77.34	157.42	00133100	6
	10	36	31.13							N376	39	176	6.25	154.42	31	000	-228.52	144.14	270.18	00113000	6
	10	36	35.28	176	6.56	153.90	31	3	000321												
	10	36	35.28	177	4.94	156.18	35	6	000331												
	10	36	35.83								39	177	4.94	156.01	35	000	-133.59	84.38	158.01	00133100	6
	10	36	35.83							N376	39	176	6.56	153.90	31	000	-225.00	151.17	271.07	00133000	6
	10	36	39.96	176	6.94	153.98	31	7	000331												
	10	36	39.96	177	5.13	155.83	35	0	000331												
	10	36	40.53								39	177	5.13	155.92	35	000	-137.11	80.86	159.18	00133100	6
	10	36	40.54							N376	39	176	6.94	153.46	31	000	-225.00	151.17	271.07	00132000	6
	10	36	44.66	177	5.31	155.13	35	4	000331												
	10	36	45.24								39	177	5.31	155.57	35	000	-137.11	84.38	160.99	00133100	6
	10	36	45.24							N376	39	176	7.31	153.63	31	000	-235.55	137.11	272.55	00133000	6
	10	36	49.34	177	5.56	154.07	35	0	000331												
	10	36	49.80								39	177	5.56	154.06	35	000	-130.08	94.92	161.03	00133100	6
	10	36	53.88	177	5.81	154.51	35	6	000331												
	10	36	54.51								39	177	5.75	153.72	35	000	-119.53	112.50	164.15	00133100	6
	10	36	58.72	177	6.00	154.07	35	0	000331												
	10	36	59.21								39	177	6.00	153.98	35	000	-140.63	94.92	169.66	00133100	6
	10	37	3.27	177	6.25	153.19	35	0	000331												
	10	37	3.92								39	177	6.19	153.81	35	000	-144.14	94.92	172.59	00133100	6
	10	37	7.95	177	6.38	152.23	34	0	000331												
	10	37	8.62								39	177	6.44	152.93	35	000	-137.11	112.50	177.36	00133100	6
	10	37	12.63	177	6.56	152.82	35	0	000331												
	10	37	13.33								39	177	6.63	151.70	34	000	-116.02	133.59	176.94	00133100	6
	10	37	17.30	177	6.75	149.94	35	0	000331												
	10	37	18.03								39	177	6.81	150.03	35	000	-87.89	159.20	180.98	00133100	6
	10	37	21.93	177	6.88	149.62	35	0	000331												
	10	37	22.59								39	177	7.00	148.80	35	000	-77.34	161.72	179.26	00133100	6
	10	37	27.33								39	177	7.13	147.30	35	000	-56.25	168.75	177.88	00133100	6
	10	37	31.86								38	177	7.31	146.16	35	000	-56.25	168.75	177.88	11033101	6

76-6-B-2

FIGURE B-2 RBTL UNPACK PROGRAM

APPENDIX C

DATA ANALYSIS STATISTICAL TECHNIQUES

APPENDIX C1

SIMPLE LINEAR REGRESSION AND CORRELATION ANALYSES

PURPOSE.

The purpose of this analysis is to quantify the relationship between some independent variable, x, and some dependent variable, y, based on the universe regression line, $y=\alpha+\beta x$, where α is the y intercept and β is the slope of the line.

PROCEDURES.

Using the method of least squares, the coefficients α and β of the regression line can be estimated from a sample of n pairs of x and y data using a and b where

$$a = \frac{(\Sigma y)(\Sigma x^2) - (\Sigma x)(\Sigma xy)}{n(\Sigma x^2) - (\Sigma x)^2}$$

and

$$b = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{n(\Sigma x^2) - (\Sigma x)^2}$$

The estimated regression line is therefore $y=a+bx$. A measure of the error involved in using the regression value to estimate y is commonly referred to as the standard error of estimate, s_e,

where

$$s_e = \sqrt{\frac{\Sigma y^2 - a(\Sigma y) - b(\Sigma xy)}{n - 2}}$$

The prediction limits or limits for individual values of y can be estimated for $x=x_o$ as follows:

$$(a + bx_o) \pm t_{\alpha/2}\, s_e \quad 1 + \frac{1}{n} + \frac{n(x_o - \bar{x})^2}{n(\Sigma x^2) - (\Sigma x)^2}$$

where $t\alpha/2$ is obtained from the t-distribution tables for n-2 degrees of freedom. These limits will contain y at $x=x_o$ with a probability of $1-\alpha$.

ASSUMPTIONS.

This analysis assumes that for each value of x, $\bar{y}$ lies on the universe regression line. It also assumes that the values of y for a given value of x are normally distributed and that the standard deviation of these values is the same for all x values.

SIMPLE CORRELATION ANALYSIS.

PURPOSE. To quantify the degree of linear association between two variables x and y, based on the coefficient of correlation.

PROCEDURES. An estimate of the population coefficient of correlation is calculated as follows:

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{n(\Sigma x^2) - (\Sigma x)^2}\sqrt{n(\Sigma y^2) - (\Sigma y)^2}}$$

More explicitly known as the Pearson Product-Moment Coefficient of Correlation, r varies between -1.0 and +1.0. Perfect correlation is indicated by $r = \pm 1.0$. When r = 0, no correlation exists.

ASSUMPTIONS. This analysis assumes that the sample regression line and the standard error of estimate are derived by the method of least squares.

APPENDIX C2

F-TEST FOR DIFFERENCES BETWEEN VARIANCES

PURPOSE.

The purpose of this test is to determine whether the variability of one set of data is significantly different from the variability of another set.

PROCEDURE.

The variances, S_1^2 and S_2^2, of each of the two sets of data are computed according to the formula

$$S_i^2 = \frac{\Sigma\ (x_{ij} - x_i)^2}{n_i - 1} \quad ; \text{ where}$$

	S_i^2	=	variance of the ith set of data
	x_{ij}	=	value of the jth observation in the ith set of data
	$\bar{x}_i$	=	mean of the ith set of data
and	n_i	=	number of observations in the ith set of data

The null hypothesis is that the variances of both sets of data are equal, i.e.,

$$H_o; \qquad S_1^2 = S_2^2.$$

The ratio of the two variances, S_1^2/S_2^2 is then formed. The larger of the two variances is placed in the numerator of this ratio. This ratio is an F-distribution characterized by two parameters $\nu 1$ and $\nu 2$. $\nu 1$, the degrees of freedom associated with the set of data with the larger variance, S_1^2, is equal to n_1-1. Similarly $\nu 2 = n_2 - 1$.

The computed value of F obtained above is compared with the tabular value of F for ν_1 and ν_2 degrees of freedom, at an $\alpha/2$ level of significance since this is a two-sided test. If the computed value of F is smaller than the corresponding tabular value, then the null hypothesis that the variances of the two sets of data are equal is not contradicted by the data.

ASSUMPTIONS.

This analysis assumes that both sets of data are independent and normally distributed.

APPENDIX C3

BARTLETT'S TEST FOR HOMOGENEITY OF VARIANCES

PURPOSE.

The purpose of Bartlett's test for homogeneity of variances is to test whether the estimated variances, S_i^2,, of each of g sets of data could have all come from the same universe, or could be represented by a common homogeneous parameter, σ^2.

PROCEDURE.

The population consists of g samples, each sample of which consists of n_i members. Each sample has an associated computed variance, S_i^2, and an associated number of degrees of freedom, $\nu_i = n_i - 1$. The null hypothesis is that the variances of each of the g samples are equal, i.e., H_0; $S_1^2 = S_2^2 = S_3^2 = \text{-------} = S_g^2$.

Using the S_i^2 and ν_i of each of the g samples, the null hypothesis is tested by means of the following mathematical models:

$$M = 2.3026 \left[\nu \log_{10} \left(\Sigma \nu_i S_i^2 / \nu \right) - \Sigma \nu_i \log_{10} S_i^2 \right]$$

$$\text{and} \quad C = 1 + \frac{1}{3(g-1)} \left\{ \Sigma \frac{1}{\nu_i} - \frac{1}{\nu} \right\} \quad \text{where } \nu = \Sigma \nu_i$$

The ratio M/C can be approximated by a chi-square distribution with g-1 degrees of freedom. Therefore, the computed M/C ratio obtained above is compared with the tabular value of chi-square for g-1 degrees of freedom, at a $\alpha/2$ level of significance, since this is a two-sided test. If the M/C ratio does not exceed the tabular value of chi-square, then the null hypothesis that the variances of the samples tested are from the same population is not contradicted by the data.

ASSUMPTIONS.

This analysis assumes that the random variations within each of the g samples are normally distributed and that the estimates of variance, S_i^2, from each of the g samples are independent. This test also assumes a minimum of five members per sample, i.

APPENDIX C4

ONE-WAY ANALYSIS OF VARIANCES

PURPOSE.

The purpose of the one-way analysis of variance is to determine whether any real differences exist between the k means of a population n.

PROCEDURE.

The population, n, is divided into k independent random subsets of sizes n_1, n_2, - - - n_k, where n_i is the number of items in the ith subset, $\bar{x}_i$ is the estimated mean of the ith subset, and s_i is the estimated standard deviation of the ith subset.

The null hypothesis is that the means of each subset (treatment means) are equal, i.e., $-H_o;\ u_1 = u_2 = \text{------} = u_k$.

The null hypothesis is tested by the F-statistic, which is constructed by the following mathematical model:

$$F = \frac{S_m^2}{S_p^2} \quad \text{where} \quad S_m^2 = \frac{\sum_{i=1}^{k} (\bar{x}_i - \bar{\bar{x}})}{k - 1}$$

$$\text{where} \quad \bar{\bar{x}} = \frac{\sum_{i=1}^{k} \bar{x}_i \ n_i}{\sum_{i=1}^{k} n_i} \quad \text{and} \quad S_p^2 = \frac{\sum_{i=1}^{k} (n_i - 1)\ S_i^2}{\sum_{i=1}^{k} n_i - k}$$

The computed value of F above is compared with the tabular value of F for ν_1=k-1 and ν_2=n-k degrees of freedom at an α level of significance. If the computed value of F is smaller than the corresponding tabular value, then the null hypothesis that the means of the k subsets are equal is not contradicted by the data. It should be noted that the analysis of variance test is always a "one-sided" test.

ASSUMPTIONS.

This analysis assumes that the observations are independent and normally distributed, with a common variance σ^2 and a mean, u_i, for each of the k subsets. It is further assumed that the errors about each subset mean, u_i, are independent and normally distributed with a zero mean and a constant variance, σ^2.

APPENDIX C5

ASPIN-WELCH TEST FOR THE DIFFERENCE BETWEEN TWO MEANS WITH UNKNOWN AND UNEQUAL SAMPLE VARIANCES (Reference 12, p.505)

PURPOSE.

This test is to determine if the means from two samples are from the same underlying population, given that the population variances are unknown and may be unequal.

PROCEDURE.

The two populations have n_1 and n_2 members, sample means of $\bar{x}_1$ and $\bar{x}_2$, true means of u_1 and u_2, and sample variances of s_1^2 and s^2 respectively. The null hypothesis is that the difference between the true means is equal to zero, i.e.- H_o; $u_1-u_2=0$.

The null hypothesis is tested by means of the t-statistic

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

and treating the above as if it had a t-distribution with degrees of freedom, ν , given by

$$\nu = \frac{1}{\frac{c^2}{n_1 - 1} + \frac{(1 - c)^2}{n_2 - 1}}$$

where

$$c = \frac{s_1^2/n_1}{s_1^2/n_1 + s_2^2/n_2}$$

The calculated values of t and ν obtained above are entered into a standard t-table for ν degrees of freedom and $\gamma/2$ level of significance (since this is a two-sided test). If the calculated value of t is less than the corresponding tabular value, then the null hypothesis that the differences of the true means is zero is not contradicted by the data.

APPENDIX D

DATA ANALYSIS REPORTS

APPENDIX D1

STATISTICAL ANALYSIS OF ARTS III (RBTL) TARGET REPORT RANGE AND AZIMUTH ERRORS (EAIR TRACKING)

by John J. Wojciech, ANA-140 (May 1975)

INTRODUCTION.

Four days of flights were conducted at NAFEC to determine the range and azimuth accuracy of the ARTS III RBTL/ASR-5 system using the Extended Area Instrumentation Radar (EAIR). As shown in figure D1-1, the horizontal flight profiles were generally the same for each of the flights, except that a different quadrant was flown each day. The vertical flight profiles shown in figure D1-2 do show some variation from day to day. Each flight consisted of two to four runs inbound and outbound using beacon code "0722." NAFEC aircraft N103 was flown on November 18 and 25, 1974, and N377 flew on November 27 and December 4, 1974. EAIR range and azimuth accuracies are listed to be 0.01 nmi (60 feet) and 0.01°, respectively. Specific design and test condition data concerning the ARTS III/ASR-5 system including the RBTL computer program will be included in the final report for activity 142-177-040.

ERROR SUMMARIES.

A validated program developed by the Data Processing Branch, ANA-550, was used to merge the EAIR data tapes with those of the ARTS III. A sample copy of this data is shown in figure 9. Specifically, EAIR range and azimuth values, translated and rotated to those of the ASR-5 (latitude: 39°26'08.0", longitude: 74°35'02.1", height: 100 feet, rotation: -9) were subtracted from "time-correlated" ARTS III target reports. The program was designed to merge only good quality (mode 3/A and mode C validity = 3; strong target indicator = 1) beacon reports. This was done for several reasons, the primary one being that over 90 percent of the beacon data were of good quality. There was no filtering initially applied with respect to the quality of the radar reports, since this did vary significantly during the testing. Finally, multiple targets within the same scan caused by reflections or "ring-around" were also not processed.

ERROR DATA GROUPING. In an effort to maintain homogenous samples, the range and azimuth errors were grouped by azimuth (290°-310°, 220°-240°, 0°-20°, and 120°-140°), flight direction (inbound, outbound), and radar condition (merged, beacon-only). Merged reports are a combination of beacon reports and radar reports, where the radar reports are based on 19 or more hits. Beacon-only reports include no radar reports. Data points or errors associated with each of these groups were randomly selected. Where less than 40 points were listed, all the data were considered for analysis.

ERROR DATA SCREENING AND DISTRIBUTION APPROXIMATION. The errors within each analysis group were checked for reasonableness. In a few instances, statistical criteria were applied to eliminate possible "outliers." All

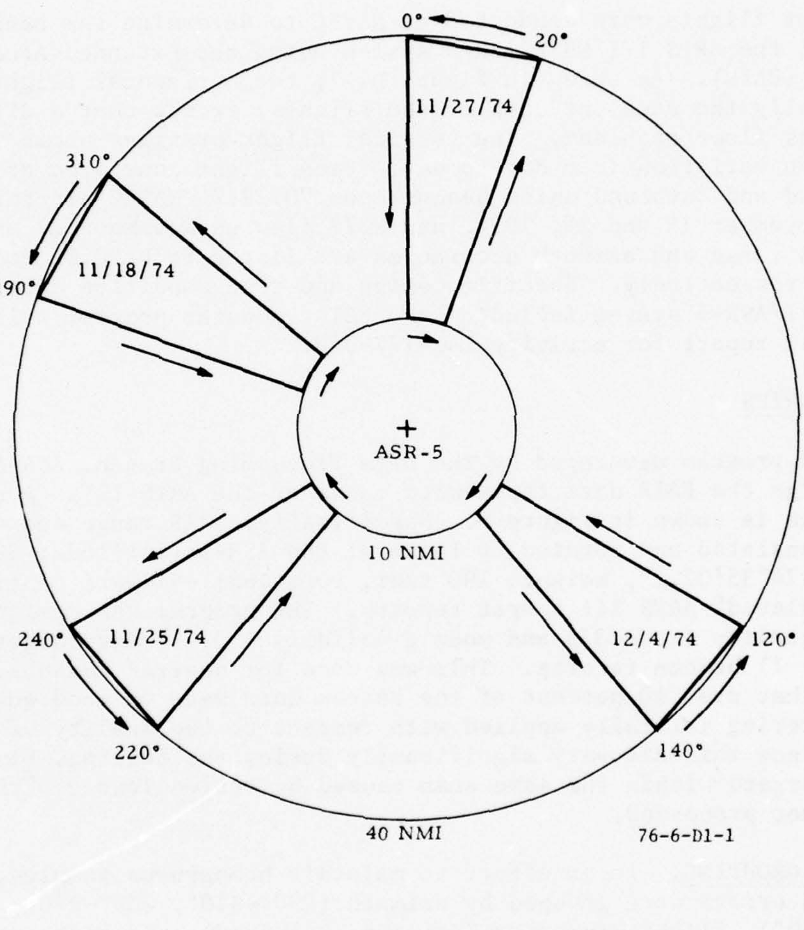


FIGURE D1-1. HORIZONTAL FLIGHT PROFILES

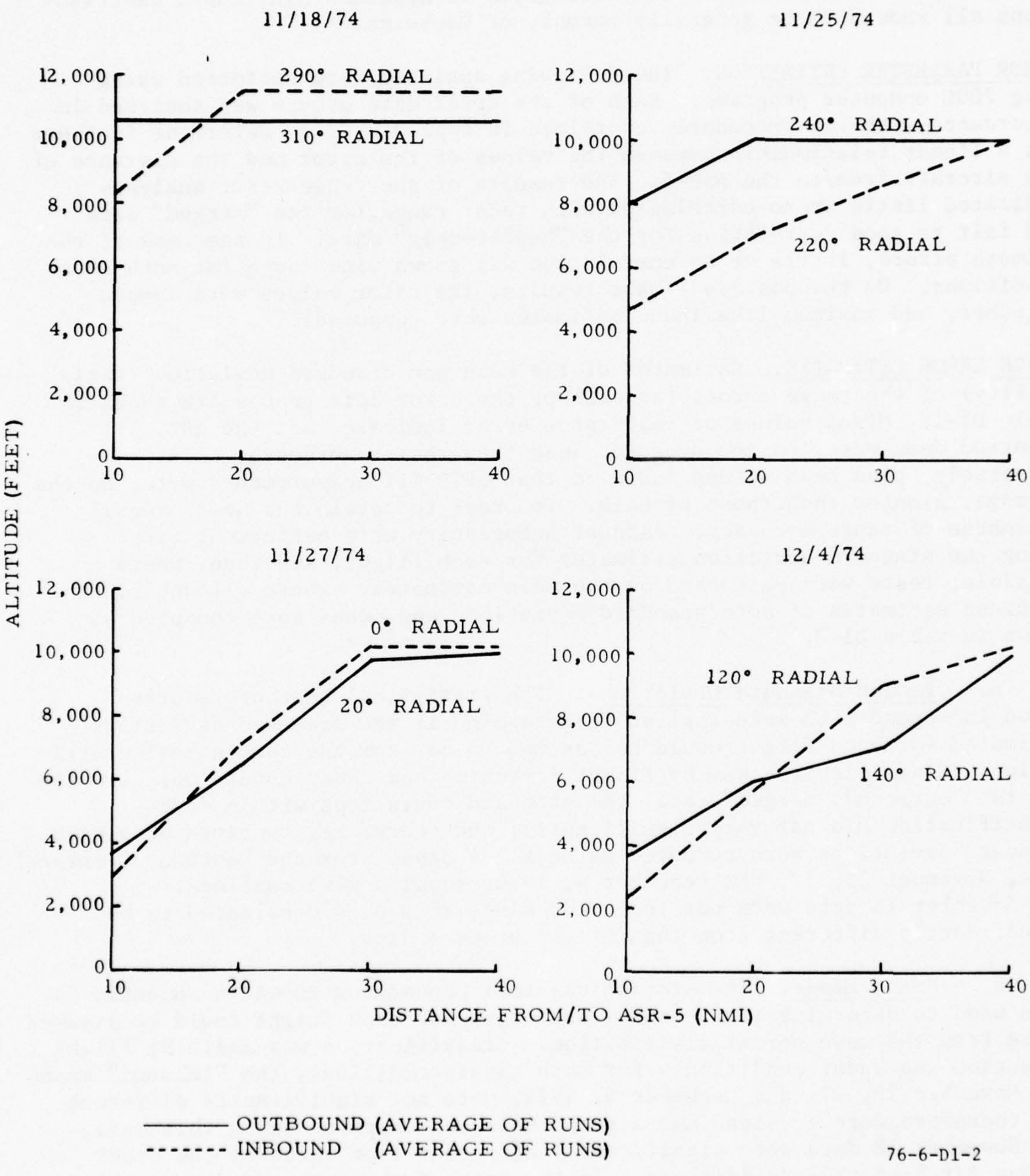


FIGURE D1-2. VERTICAL FLIGHT PROFILES

points selected were approved and the error distributions were declared to be homogeneous. Finally, a check was made of the distributions of the errors in each group. As indicated by the histograms in appendix D1A, these distributions all showed to be generally normal, or Gaussian.

ERROR PARAMETER ESTIMATION. The following analyses were performed using Wang 700C computer programs. Each of the error data groups was analyzed in accordance with the procedures contained in appendix C1 to determine if there was a linear relationship between the values of the error and the distance of the aircraft from/to the ASR-5. The results of the range error analyses indicated little or no correlation with radar range for the "merged" data and fair to good correlation for the "beacon-only" data. In the case of the azimuth errors, little or no correlation was shown with range for both radar conditions. On the basis of these results, the error values were lumped together, and maximum likelihood estimates were computed.

RANGE ERROR ESTIMATES. Estimates of the mean and standard deviation (variability) of the range errors for each of the error data groups are shown in table D1-1. Minus values of mean range error indicate that the ARTS III reported data were, on the average, less than that recorded by EAIR. Conversely, plus mean values indicate that ARTS III measurements were, on the average, greater than those of EAIR. In order to obtain the best overall estimates of range accuracy, tests of homogeneity were performed; first using the standard deviation estimates for each flight, and then, where possible, tests were performed on the mean estimates. Where allowable, combined estimates of both standard deviations and means were computed as shown in table D1-2.

a. Pooled Standard Deviations. The statistical test procedures shown in appendix C3 were applied to determine if the standard deviations estimated for each flight could be assumed to be from the same normal distribution. Classification was by flight direction and radar condition. Except for the "outbound, merged" data, the standard deviations within each classification did not vary significantly, and therefore, combined or pooled standard deviations were computed using all 4 days. For the "outbound, merged" case, November 25, 27, and December 4, 1974, results were combined. The November 18 data were not included, since they were considered to be significantly different from that of the other 3 days.

b. Grand Means. The statistical test procedures shown in appendix C4 were used to determine if the means estimated for each flight could be assumed to be from the same normal distribution. Classification was again by flight direction and radar condition. For both radar conditions, the "inbound" means for November 25, 27, and December 4, 1974, were not significantly different and therefore were combined and a grand mean was computed using this data. The November 18 data were significantly different from those of the other 3 days for both radar conditions. In the case of the outbound data, a high degree of variability was indicated for both radar conditions, and therefore, these data were not combined.

TABLE D1-1. RANGE ERROR ESTIMATES (nmi)

Test Date (Azimuth)	Inbound						Outbound					
	Merged			Beacon-Only			Merged			Beacon-Only		
	N	$\overline{X}$ (nmi)	S (nmi)	N	$\overline{X}$ (nmi)	S (nmi)	N	$\overline{X}$ (nmi)	S (nmi)	N	$\overline{X}$ (nmi)	S (nmi)
11/18/74 (290°-310°)	35	-0.025 (-152)	0.026 (158)	30	0.100 (608)	0.030 (182)	28	0.077 (468)	0.031 (188)	32	0.213 (1294)	0.030 (182)
11/25/74 (220°-240°)	32	-.086 (-523)	.022 (134)	26	-.057 (-346)	.027 (164)	32	-.038 (-231)	.017 (103)	35	.009 (55)	.031 (188)
11/27/74 (0°-20°)	50	-.095 (-577)	.024 (146)	23	-.048 (-292)	.022 (134)	38	-.018 (-109)	.019 (115)	26	.018 (109)	.019 (115)
12/4/74 (120°-140°)	30	-.099 (-602)	.019 (115)	32	-.061 (-371)	.028 (170)	37	-.067 (-407)	.012 (73)	31	-.038 (-231)	.030 (182)

*ARTS III target reports minus EAIR from 10 to 40 nmi from the ASR-5.

Legend: N - Sample size
$\overline{X}$ - Mean
S - Standard Deviation
( ) - Feet

Formulas: $\overline{X} = \frac{\Sigma X}{N}$

$$S = \sqrt{\frac{\Sigma (X - \overline{X})^2}{N - 1}}$$

TABLE D1-2. COMBINED RANGE ERROR ESTIMATES[1]

Flight Direction	Radar Condition	Pooled Standard Deviation S_p (nmi)	Grand Mean $\bar{\bar{X}}$ (nmi)	Tolerance Limits $\bar{\bar{X}} - 3S_p$ (nmi)	$\bar{\bar{X}} + 3S_p$ (nmi)	$\bar{\bar{X}} \pm 3S_p$ $(6S_p)$ (nmi)
Inbound	Beacon-Only	0.027[2] (164) N=111	-0.056[3] (-340) N=81	-0.137 (-832)	0.025 (152)	0.162 (934)
	Merged	.023[2] (140) N=147	- .094[3] (-571) N=112	- .163 (-990)	.025 (-152)	.138 (839)
Outbound	Beacon-Only	.028[2] (170) N=124	Note[4]			.168 (1021)
	Merged	.016[3] (97) N=107	Note[4]			.096 (583)

[1]ARTS III target reports minus EAIR from 10 to 40 nmi from the ASR-5. The procedures used to determine homogeneity of standard deviations and means are given in appendixes C3 and C4, respectively. (level of significance = .01).

[2]All four days were combined.

[3]November 25, 27, and December 4, 1974, data were combined (November 18 mean was significantly different).

[4]*Significant differences precluded combining this data.*

Legend: ( ) = Feet
N = Combined sample size

Formulas

$$S_p = \sqrt{\frac{(N_1-1)S_1^2 + (N_2-1)S_2^2 + \ldots + (N_k-1)S_k^2}{N_1 + N_2 + ;;; + N_k - k}}$$

$$\bar{\bar{X}} = \frac{N_1 \bar{X}_1 + N_2\bar{X}_2 2 + \ldots + N_k\bar{X}_k}{N_1 + N_2 + \ldots\ldots + N_k}$$

c. Tolerance Limits. Using the grand means and pooled standard deviations, 3-sigma limits were calculated as shown in table D1-2. In addition, the range of errors based on the 3-sigma limits is given. The 3-sigma limits indicate that at least 99 percent of the individual range errors associated with the classifications listed, can be expected to be within these limits. The difference between the 3-sigma limits infers that at least 99 percent of the range errors can be expected to be within the range derived.

AZIMUTH ERROR ESTIMATES. Estimates of the mean and standard deviation (variability) of the azimuth errors for each of the error data groups is shown in table D1-3. Plus mean values indicate that the ARTS III reported data were, on the average, greater (more clockwise) than that recorded by EAIR. Again, tests of homogeneity were performed to determine if the test results could be combined to provide a more precise estimate of azimuth accuracy. The combined estimates are shown in table D1-4.

a. Pooled Standard Deviations. The statistical test procedures shown in appendix C3 were again applied to determine if the standard deviations within each "flight direction, radar condition" test classification could be combined. Except for "outbound, beacon-only" data, the standard deviations from all 4 days showed to be homogenous. A combined estimate was obtained for the "outbound, beacon-only" case, however, using the results from November 18, 27, and December 4, 1974. The November 25, 1974, standard deviation was significantly different from those of the other 3 days.

b. Grand Means. The procedures shown in appendix C4 were used again to statistically test for significant differences between the means within each test classification. For each classification, the November 18, 25, and December 4 means can be considered from the same normal distribution. The November 27 means were significantly different from those of the other 3 days.

c. Tolerance Limits. The 3-sigma limits and the differences between these limits are also given in table D1-4.

COMPARISON TESTING.

These analyses were performed using Wang 700C computer programs. Based on the statistical test procedures described in appendices C2 and D1B, the range and azimuth error pooled standard deviations and grand means given in tables D1-2 and D1-4, respectively, were compared to determine the effects of flight direction and radar condition. The results of these analyses are shown in table D1-5.

INBOUND VERSUS OUTBOUND.

a. Range Errors. Based on the beacon-only data, flight direction does not affect the variability of the range errors; however, the "merged" data indicate that the "inbound" error variation is significantly different than the "outbound" error variation. Although tests of significance were not performed, due to the high variability of the "outbound" means from flight to

TABLE D1-3. AZIMUTH ERROR ESTIMATES (DEGREES)[1]

Test Date (Azimuth)	Inbound						Outbound					
	Merged			Beacon-Only			Merged			Beacon-Only		
	N	$\overline{X}$ (deg.)	S (deg.)	N	$\overline{X}$ (deg.)	S (deg.)	N	$\overline{X}$ (deg.)	S (deg.)	N	$\overline{X}$ (deg.)	S (deg.)
11/18/74 (290°-310°)	35	0.99	0.171	30	1.12	0.225	28	0.88	0.182	32	0.97	0.197
11/25/74 (220°-240°)	32	1.03	.111	26	1.16	.161	32	.79	.156	35	.88	.126
11/27/74 (0°-20°)	25	1.04	.176	23	1.25	.164	38	1.02	.158	26	1.17	.228
12/4/74 (120°-140°)	30	.93	.139	32	1.05	.139	37	.88	.120	31	.97	.144

[1]ARTS III target reports minus EAIR from 10 to 40 nmi from the ASR-5.

Legend:
- N - Sample Size
- $\overline{X}$ - Mean
- S - Standard Deviation

Formulas:

$$\overline{X} = \frac{\Sigma X}{N}$$

$$S = \sqrt{\frac{\Sigma(X - \overline{X})^2}{N - 1}}$$

TABLE D1-4. COMBINED AZIMUTH ERROR ESTIMATES[1]

Flight Direction	Radar Condition	Pooled Standard Deviation S_p (degrees)	Grand Mean $\bar{\bar{X}}$ (degrees)	Tolerance Limits		
				$\bar{\bar{X}} - 3S_p$ (degrees)	$\bar{\bar{X}} + 3S_p$ (degrees)	$\bar{\bar{X}} \pm 3S_p$ $(6S_p)$ (degrees)
Inbound	Beacon-Only	0.176[2] N=111	1.11[3] N=88	0.58	1.64	1.06
	Merged	.151[2] N=122	.99[3] N=97	.54	1.44	.91
Outbound	Beacon-Only	.191[4] N=89	.93[3] N=98	.36	1.50	1.15
	Merged	.154[2] N=135	.85[3] N=97	.39	1.31	.92

[1] ARTS III target reports minus EAIR from 10 to 40 nmi from the ASR-5. The procedures used to determine homogeneity of standard deviations and means are given in appendixes C3 and C4, respectively (level of significance = .01).

[2] All 4 days were combined.

[3] November 18, 25, and December 4, 1974, data were combined (November 27 mean significantly different).

[4] November 18, 27, and December 4, 1974, data were combined (November 25 standard deviation significantly different).

Legend: N = Combined sample size.

Formulas

$$S_p = \sqrt{\frac{(N_1-1)S_1^2 + (N_2-1)S_2^2 + \ldots + (N_k-1)S_k^2}{N_1 + N_2 + \ldots\ldots\ldots\ldots N_k - k}}$$

$$\bar{\bar{X}} = \frac{N_1\bar{X}_1 + N_2\bar{X}_2 + \ldots + N_k\bar{X}_k}{N_1 + N_2 + \ldots\ldots N_k}$$

TABLE D1-5. RESULTS OF COMPARISON TESTS[1]

Error	Parameter	Inbound vs Outbound		Beacon-Only vs Merged	
		Beacon-Only	Merged	Inbound	Outbound
Range	Standard Deviation	No Significance (.05)	Significance (.01)	No Significance (.05)	Significance (.01)
	Mean	Note 2	Note 2	Significance (.01)	Note 2
Azimuth	Standard Deviation	No Significance (.05)	No Significance (.05)	No Significance (.05)	No Significance (.05)
	Mean	Significance (.01)	Significance (.01)	Significance (.01)	Significance (.01)

[1]ARTS III target reports minus EAIR from 10 to 40 nmi from the ASR-5. Standard deviation and mean tests were performed in accordance with the procedures given in appendices C2 and D1B, respectively.

[2]Outbound means varied significantly from flight to flight, and therefore grand means were not computed.

Legend: ( ) - Level of significance

flight, table D1-1 does show that in each case, the "inbound" means were much different from the "outbound" means for both radar conditions.

b. Azimuth Errors. For both radar conditions, error variability was independent of flight direction. However, for both radar conditions, the "inbound" and "outbound" means differed significantly.

MERGED VERSUS BEACON-ONLY.

a. Range Errors. Based on the "inbound" data, it is found that the radar condition does not affect the variability of the range errors, however, the "outbound" data indicates that the variation of the beacon-only errors was significantly different from that the "merged" errors. For the mean errors, the "inbound" data did show significant difference, and the "outbound" data from table D1-1 show show that for each flight, the "merged" means were much different than the "beacon-only" means.

b. Azimuth Errors. For both flight directions, error variability is not significantly affected by radar condition. However, for both flight directions, the "merged" means and "beacon-only" means differed significantly.

SUMMARY OF RESULTS.

Under similar operational and environmental conditions as those specified in this report, the estimated ARTS III (RBTL) target report accuracies are as follows:

RANGE ACCURACY. Range errors should not vary more than approximately 1,000 feet ($\pm$500 feet of the mean error). The inherent variability of the "merged" errors appears to be slightly less than that of the "beacon-only" errors. Also, error variability seems to be generally independent of flight direction.

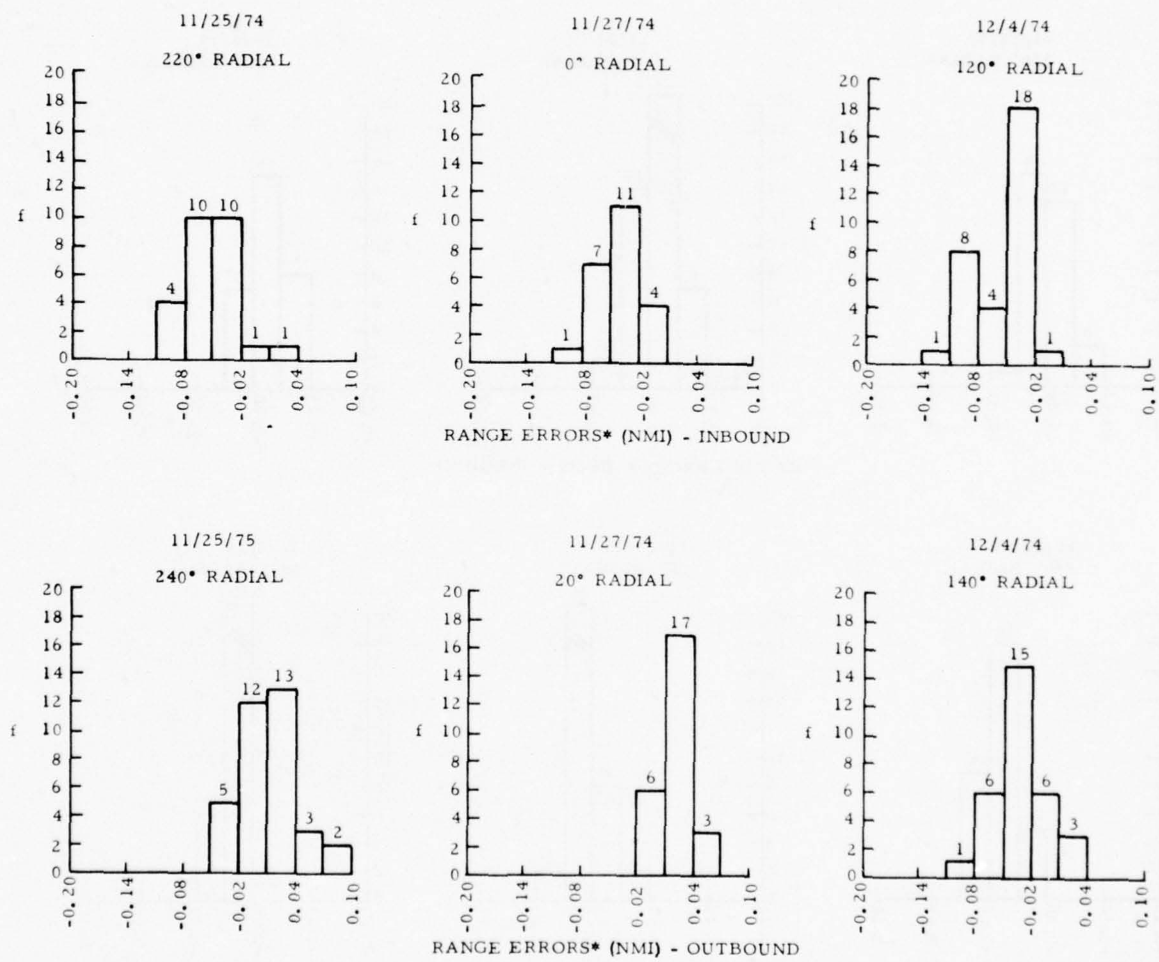
The range of mean errors, or biases, was from approximately +0.2 nmi (+1,200 feet) to -0.1 nmi (-600 feet). On the average, the "merged" errors were always less (more negative) than the "beacon-only" errors. Comparing flight directions, the "inbound" errors were also always less (more negative on the average) than the "outbound" errors.

AZIMUTH ACCURACY. Azimuth errors should not vary more than approximately 1° ($\pm$0.5° of the mean error). This variability does not seem to be influenced significantly by either radar condition or flight direction.

The range of mean errors or biases was from 1.2° to 0.8°. On the average, the "beacon-only" errors were always greater (more clockwise) than the "merged" errors. Comparing flight directions, the "inbound" errors were also always greater (more clockwise) on the average than the "outbound" errors.

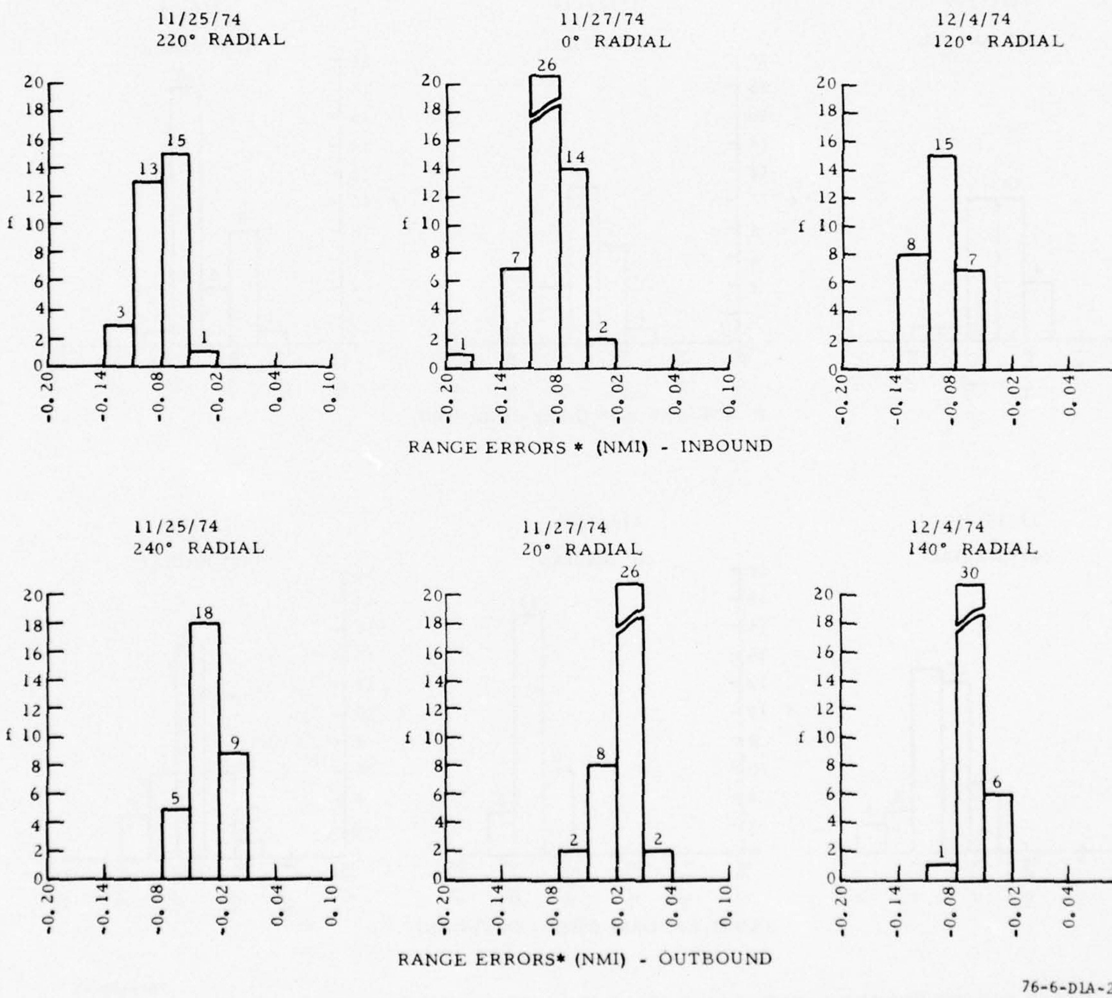
APPENDIX D1A

HISTOGRAMS OF RANGE AND AZIMUTH ERRORS



* ARTS III TARGET REPORT = MINUS EAIR FROM 10 TO 40 NMI FROM THE ASR-5.

FIGURE D1A-1. HISTOGRAMS OF RANGE ERRORS (BEACON-ONLY)



* ARTS III TARGET REPORTS MINUS EAIR FROM 10 TO 40 NMI FROM THE ASR-5

FIGURE D1A-2. HISTOGRAMS OF RANGE ERRORS (MERGED)

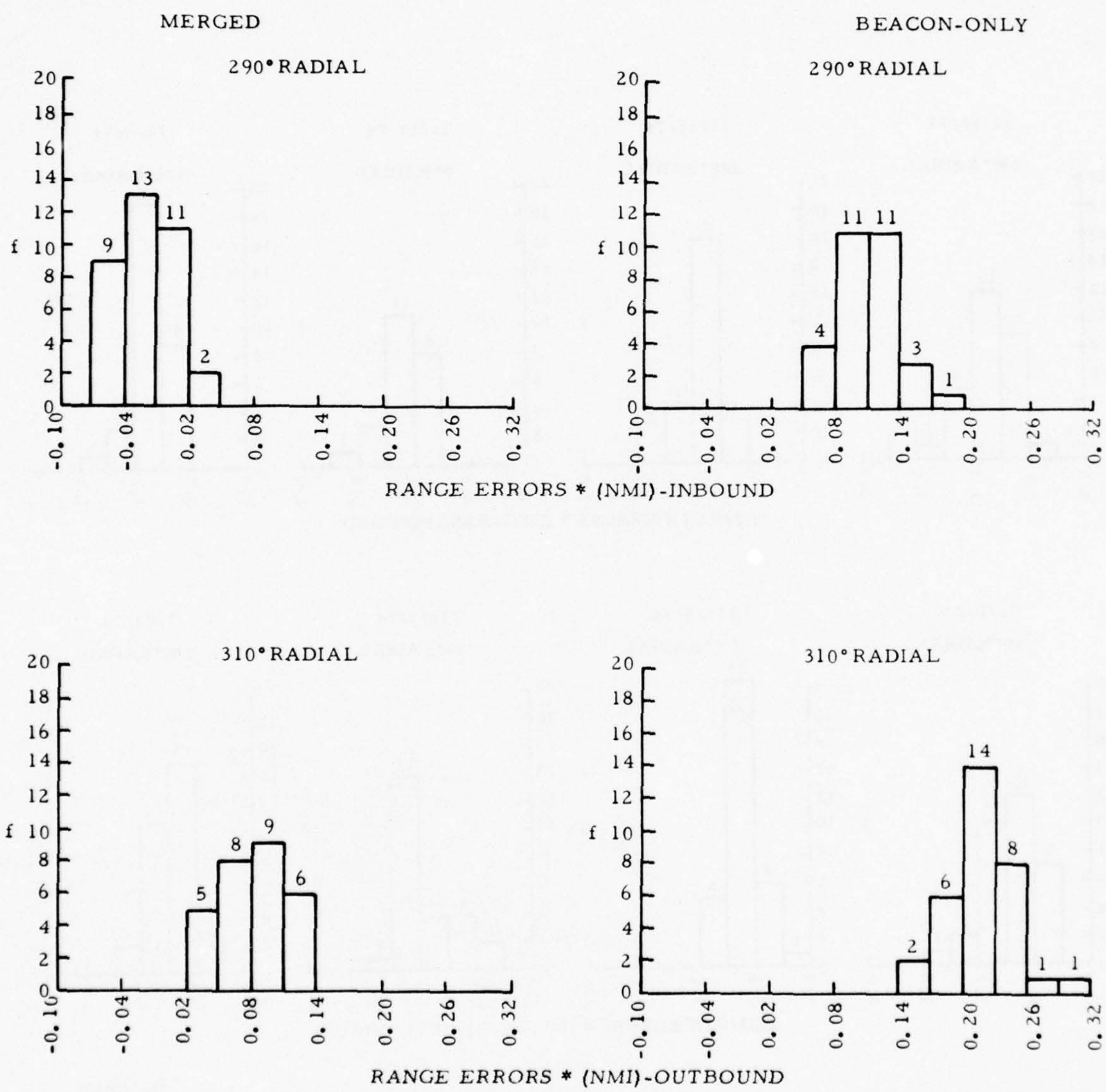
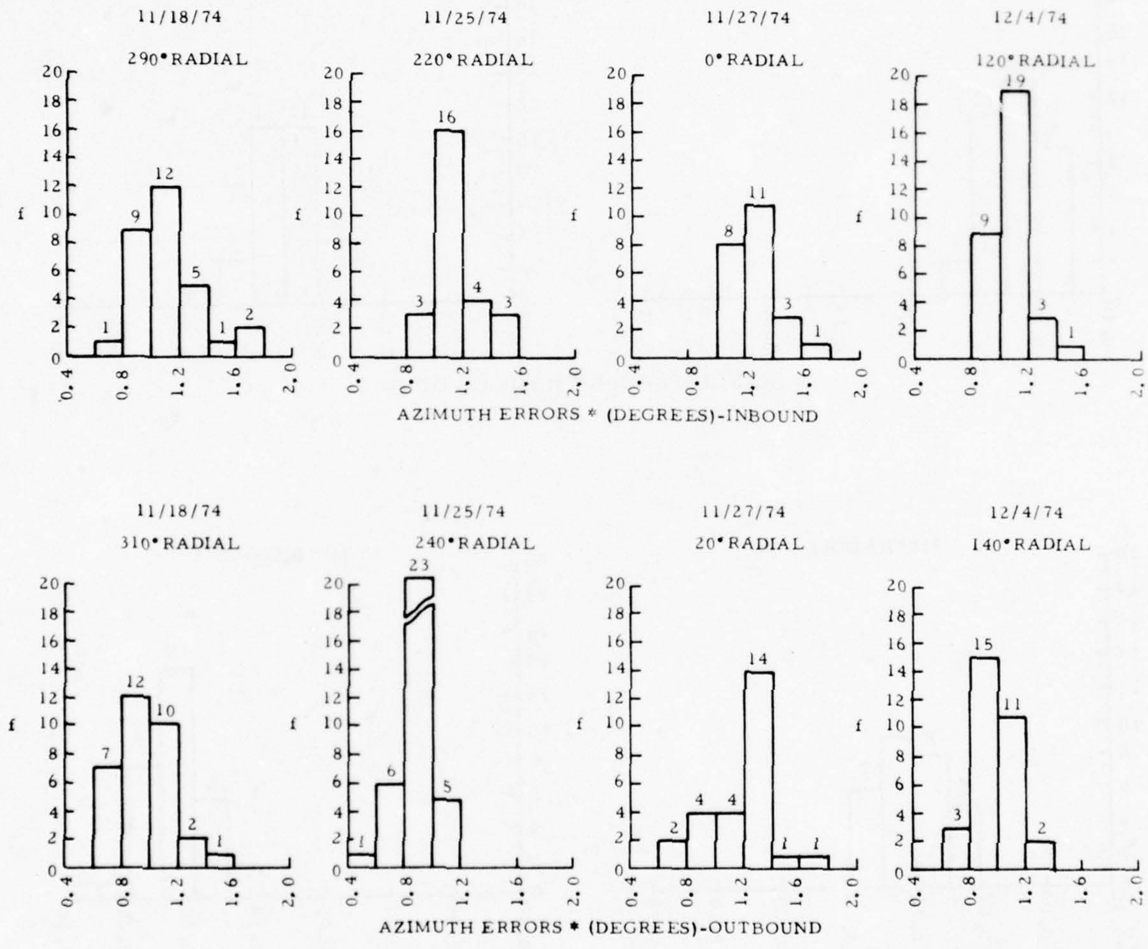
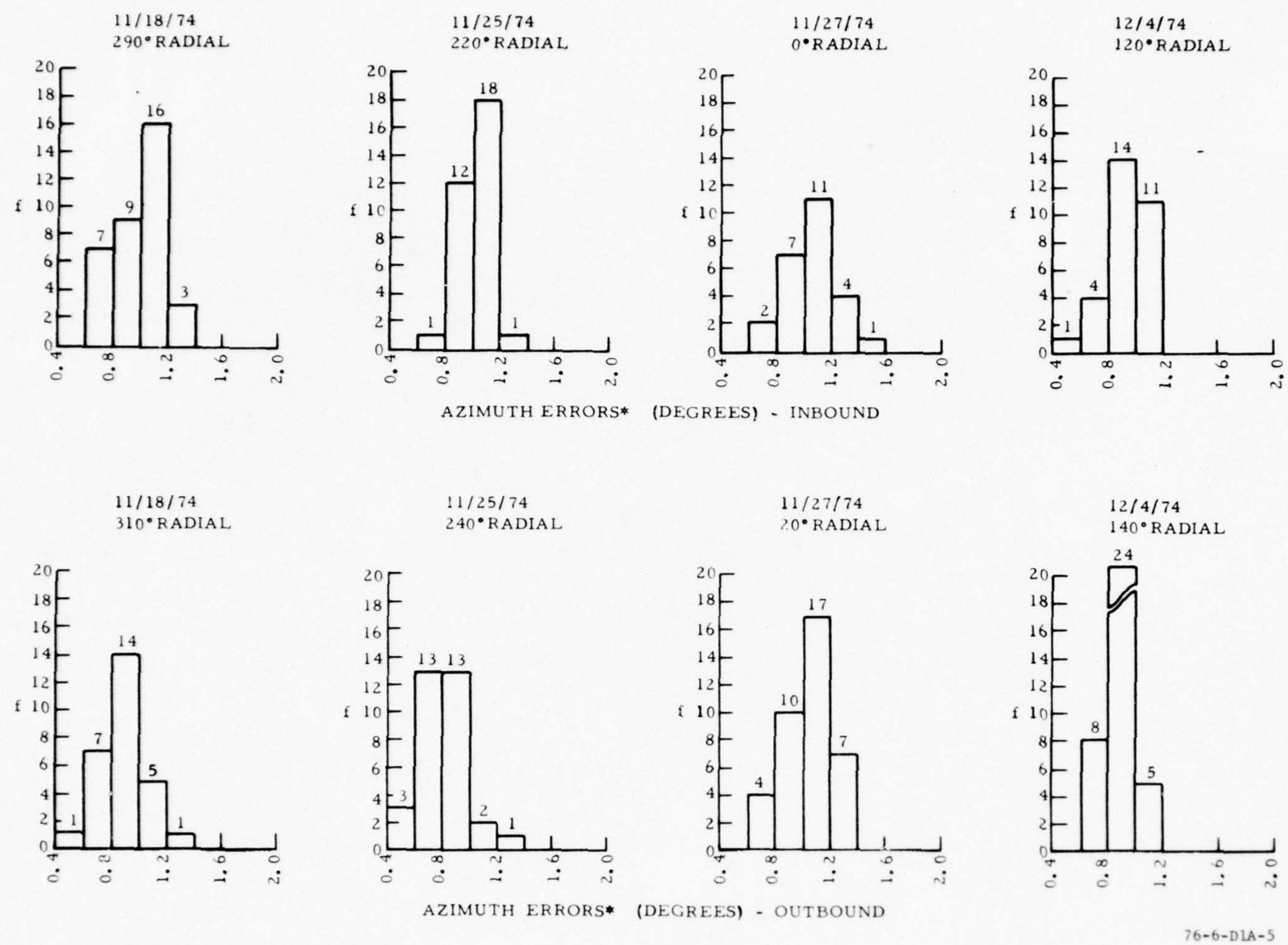


FIGURE D1A-3. HISTOGRAMS OF RANGE ERRORS FOR NOVEMBER 18,1975



*ARTS III TARGET REPORTS MINUS EAIR FROM 10 TO 40 NMI FROM THE ASR-5.

FIGURE D1A-4. HISTOGRAMS OF AZIMUTH ERRORS (BEACON-ONLY)



* ARTS III TARGET REPORTS MINUS EAIR FROM 10 TO 40 NMI FROM THE ASR-5

FIGURE DIA-5. HISTOGRAMS OF AZIMUTH ERRORS (MERGED)

APPENDIX D1B

Z-TEST FOR THE DIFFERENCE BETWEEN TWO MEANS (KNOWN VARIANCES)

PURPOSE.

The purpose of this Z-test is to determine if the means from two samples are from the same underlying population, given that the population variances are known.

PROCEDURE.

The two populations have n_1 and n_2 members, sample means of $\bar{x}_1$ and $\bar{x}_2$, true means of μ_1 and μ_2, and known variances of σ_1^2 and δ_2^2, respectively.

The null hypothesis is that the difference between the true means is equal to zero; i.e. - H_o; $\mu_1 - \mu_2 = 0$

The null hypothesis is tested by means of the Z statistic:

$$Z = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$

The Z value obtained from the above is entered into a standard Z table, or table of normal deviates, and the corresponding value ($\sigma/2$) obtained. If this is lower than the critical $\sigma/2$ value agreed upon, then the null hypothesis that the differences of the sample means equal the differences of the true means is not contradicted by the data. The $\sigma/2$ significance level is used, because this is a two-sided test.

ASSUMPTIONS.

This analysis assumes that the two samples are independent; however, they need not be normally distributed, since the Central Limit Theorem states that the means of samples ($N > 10$) from a population are normally distributed, and likewise the differences between them.

APPENDIX D2

STATISTICAL ANALYSIS OF ARTS III (RBTL) TARGET REPORT RANGE AND AZIMTUH ERRORS (THEODOLITE TRACKING)

by John J. Wojciech, ANA-140 (July, 1975)

INTRODUCTION.

Two days of flights were conducted at NAFEC to determine the range and azimuth accuracy of the ARTS III RBTL/ASR-5 system using the Theodolites. Two NAFEC aircraft were used to fly several runs of the flight profile shown in figure D2-1. Table D2-1 gives a summary of the general flight conditions including Theodolite accuracy data which vary depending on aircraft position. Specific design and test condition data concerning the ARTS III/ASR-5 system including the RBTL computer program will be included in the final report for activity 142-177-040.

ERROR SUMMARIES.

ARTS III target report data are unpacked using a program developed by the Data Processing Branch, ANA-550. A sample copy of the output is shown in figure B-2. The ARTS III tape is then merged with the Theodolite data tapes, one for each Theodolite pair, to provide a summary of the range and azimuth errors as shown in figure D2-2. Specifically, Theodolite range and azimuth values, translated and rotated to those of the ASR-5 (x=103,651.8 feet; y=107,858.8 feet; Z=10,100 feet; Rotation=307.7°), were subtracted from "time-correlated" ARTS III target reports. The program, also developed by ANA-550, merges only good quality beacon reports (mode 3/A and mode C validity = 3; strong target indicator = 1). This was done for several reasons, the primary one being that over 90 percent of the beacon data was of good quality. There was no filtering initially applied with respect to the quality of the radar reports, since this did vary significantly during the testing. Finally, multiple targets within the same scan caused by reflections or "ring-around" were also not processed.

ERROR DATA GROUPING.

In an effort to maintain homogeneous samples, the range and azimuth errors were grouped by azimuth (300°-320°, 200°-220°, 20°-40°, and 100°-120°), test date (November 6 and 8, 1974), beacon code (1211 and 0722), flight direction (inbound and outbound) and radar condition (beacon-only and merged).

ERROR DATA SCREENING AND DISTRIBUTION APPROXIMATION.

The errors within each analysis group were checked for reasonableness. There were a couple of obvious cases where tracking was lost. These values and those few that failed to meet the "outlier test" ("Quality Control and Industrial Statistics," by A. J. Duncan, Richard D. Irwin, Inc., 1965, page 639) were removed from the analysis. The resultant errors for each data group were normally distributed.

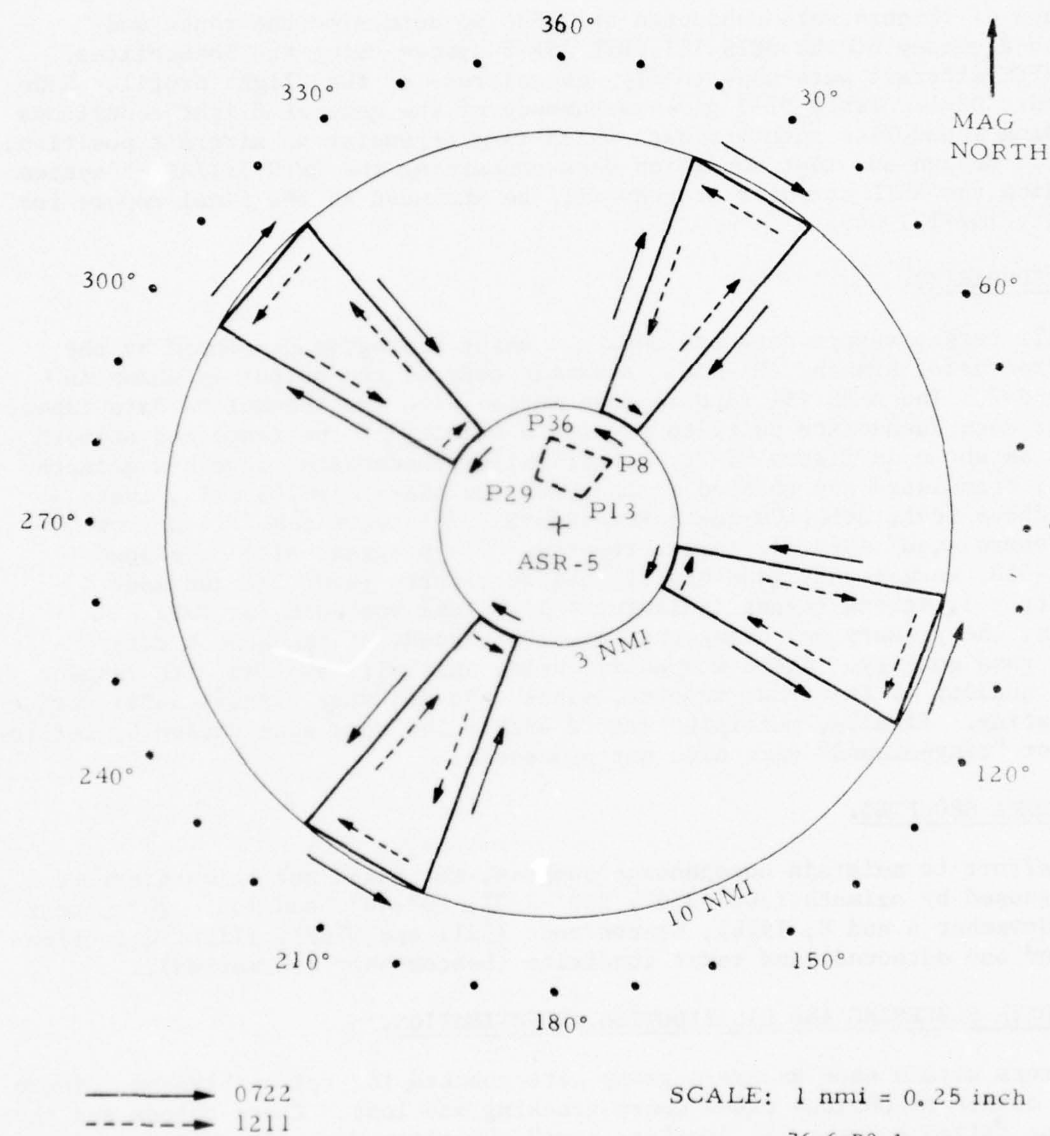


FIGURE D2-1. FLIGHT PROFILES (THEODOLITE)

TABLE D2-1. FLIGHT SUMMARY (11/6/74 & 11/8/74)

Aircraft ID	Beacon Code	Altitude[1] (Feet)	Theodolite Pair	Magnetic Azimuth Sector (°)	Maximum Range Error (Feet)[2]
N103	0722	3,500	P29/P13	20°-40°	8 to 300
				200°-220°	60 to 450
			P8/P13	300°-320°	55 to 550
				100°-120°	45 to 500
N377 (11/6/74)	1211	3,000	P36/P8	20°- 40°	13 to 200
				200°-220°	85 to 450
N376 (11/8/74)			P29/P36	300°-320°	4 to 400
				100°-120°	85 to 625

[1] Groundspeeds generally varied between 175 and 200 knots.

[2] Accuracy data were calculated using the method described on page 11-2-7 of FAA Publication, "Technical Facilities at NAFEC", dated July 1, 1969. Both minimum and maximum distances from the baselines were considered, and an "e" value of 43.49×10^{-5} corresponding to magnetic tape readings was used.

FLT 11/08/74 PD 05/05/75 ARTS H-046 REF D083(0722) TST D082 (1211) 2 TARGET DATA

TIME HR	TIME MN	TIME SEC	AIRCRAFT 1 RANGE REF (NMI)	AIRCRAFT 1 RANGE ERROR (NMI)	AIRCRAFT 1 AZIMUTH REF (DEG)	AIRCRAFT 1 AZIMUTH ERROR (DEG)	AIRCRAFT 1 HEIGHT REF (FT)	AIRCRAFT 1 HEIGHT ERROR (FT)	AIRCRAFT 2 RANGE REF (NMI)	AIRCRAFT 2 RANGE ERROR (NMI)	AIRCRAFT 2 AZIMUTH REF (DEG)	AIRCRAFT 2 AZIMUTH ERROR (DEG)	AIRCRAFT 2 HEIGHT REF (FT)	AIRCRAFT 2 HEIGHT ERROR (FT)	AIRCRAFT SEPARATION REF (NMI)	AIRCRAFT SEPARATION ERROR (NMI)
14	16	0.31	3.06	0.24	18.63	0.11	3500	28	3.45	0.09	4.09	1.02	2206	22	0.91	-0.08
14	16	4.99	3.31	0.28	18.11	0.07	3500	10	3.69	0.24	7.31	1.17	2306	-11	0.76	-0.03
14	16	14.35	3.56	0.12	18.90	0.43	3500	22	3.75	0.13	13.31	0.96	2603	42	0.40	-0.02
14	16	37.77	4.56	0.08	20.30	0.27	3500	14	4.31	0.06	24.52	0.11	3100	21	0.41	0.01
14	16	51.81	5.31	0.22	21.01	0.28	3500	56	5.06	0.23	28.61	0.30	3003	-18	0.73	0.03
14	16	56.51	5.38	0.07	20.92	0.07	3500	48	5.30	0.26	29.51	0.19	3000	29	0.80	-0.00
14	17	1.19	5.75	0.26	21.09	0.26	3500	59	5.37	0.10	30.30	0.05	3000	46	0.97	0.06
14	17	5.89	5.94	0.23	21.01	0.20	3500	44	5.68	0.18	31.44	0.35	3000	34	1.09	0.06
14	17	15.23	6.25	0.14	20.92	0.33	3500	-4	6.18	0.22	32.86	0.40	3000	-20	1.29	0.04
14	17	19.93	6.56	0.23	20.65	0.27	3500	-15	6.37	0.18	33.30	0.28	3000	-10	1.44	0.05
14	17	29.31	6.94	0.22	20.39	0.44	3500	-11	6.87	0.22	34.27	0.38	3000	-2	1.67	0.05
14	17	43.39	7.56	0.24	19.60	0.17	3500	22	7.62	0.28	35.15	0.45	3000	-12	2.05	0.11
14	17	48.04	7.75	0.20	19.34	-0.01	3500	24	7.81	0.24	35.16	0.37	3000	-17	2.14	0.11
14	17	52.74	7.94	0.17	19.51	0.24	3500	14	7.99	0.19	35.41	0.58	3000	-16	2.20	0.10
14	18	25.58	9.38	0.11	19.60	0.38	3500	4	9.56	0.12	35.67	0.60	3000	-12	2.65	0.07
14	18	30.24	9.56	0.13	19.42	0.16	3500	23	9.74	0.07	35.26	0.14	3000	-20	2.67	0.02
14	18	34.92	9.75	0.07	19.16	-0.11	3500	10	10.05	0.14	35.50	0.34	3000	-22	2.83	0.11
14	18	39.60	9.94	0.03	19.60	0.32	3500	11	10.24	0.11	35.59	0.40	3000	-9	2.82	0.04
14	18	44.29	10.19	0.11	19.51	0.22	3500	22	10.49	0.12	35.68	0.44	3000	-17	2.92	0.07
14	19	7.75	11.13	0.08	22.41	0.53	3500	-47	11.49	0.16	33.32	0.19	3000	-22	2.18	-0.03
14	19	17.13	11.19	0.01	24.96	0.58	3500	-26	11.63	0.10	31.58	0.53	3000	-27	1.39	0.02
14	19	21.80	11.38	0.18	26.46	0.73	3500	2	11.69	0.17	30.23	0.35	3000	-41	0.82	-0.06
14	19	26.51	11.38	0.16	27.51	0.44	3500	16	11.50	0.04	28.92	0.19	3000	-20	0.31	-0.10
14	19	31.19	11.31	0.14	28.39	-0.04	3400	-65	11.33	0.01	28.01	0.35	3000	-41	0.08	-0.13
14	19	40.71	11.25	0.12	31.82	0.57	3500	9	10.99	0.07	26.10	0.15	3000	-28	1.14	0.10
14	19	45.39	11.06	-0.01	33.13	0.52	3500	3	10.68	0.03	26.01	0.54	3000	-27	1.40	-0.01
14	19	50.09	10.94	0.02	34.28	0.35	3500	-34	10.55	0.15	25.66	0.39	3000	-38	1.66	-0.03
14	19	54.76	10.75	-0.04	35.33	0.24	3500	-38	10.12	0.01	25.67	0.29	3000	-55	1.87	-0.03
14	19	59.46	10.56	0.04	36.74	0.67	3500	-18	9.99	0.16	26.01	0.40	3000	-58	2.00	0.03
14	20	4.13	10.31	0.06	37.27	0.49	3500	-26	9.61	0.05	25.94	0.10	3000	-41	2.09	0.07
14	20	8.81	10.13	0.08	37.79	0.55	3500	-39	9.31	0.04	26.28	0.25	3000	-28	2.11	0.07
14	20	13.49	9.75	0.01	38.06	0.62	3500	-6	9.12	0.13	26.37	0.17	3000	-32	2.02	0.04
14	20	18.17	9.44	-0.02	37.71	0.31	3500	10	8.87	0.15	26.55	0.23	3000	-11	1.87	-0.04
14	20	27.55	8.88	-0.03	37.88	0.70	3400	-71	8.18	0.04	26.81	0.29	3000	-22	1.78	0.03
14	20	36.92	8.38	0.04	37.44	0.44	3500	35	7.77	0.17	27.07	0.38	3000	-17	1.58	-0.03
14	20	41.60	8.06	0.01	37.44	0.46	3500	23	7.49	0.17	27.24	0.47	3000	-9	1.50	-0.05
14	20	46.28	7.94	0.16	37.35	0.35	3500	8	7.18	0.13	27.10	0.24	3000	-16	1.55	0.05
14	20	50.98	7.63	0.15	37.62	0.55	3500	1	6.93	0.15	27.92	0.97	3000	-9	1.41	-0.03
14	20	55.66	7.25	0.03	38.14	0.95	3500	-6	6.62	0.12	27.07	0.06	3000	-12	1.48	0.07
14	21	0.34	7.06	0.12	38.06	0.73	3500	-14	6.37	0.13	27.16	0.13	3000	-13	1.45	0.08
14	21	5.02	6.81	0.16	38.06	0.57	3500	-10	6.12	0.15	27.07	0.08	3000	-17	1.42	0.08
14	21	9.70	6.56	0.18	38.58	0.94	3500	-7	5.87	0.17	27.15	0.20	3000	-20	1.42	0.11
14	21	14.39	6.25	0.15	38.85	1.13	3500	-10	5.56	0.13	26.98	0.08	3000	-12	1.40	0.13
14	21	19.07	5.94	0.11	38.32	0.58	3500	-2	5.30	0.14	26.90	0.03	3000	-3	1.28	0.05
14	21	23.77	5.69	0.15	39.38	1.72	3500	24	5.05	0.15	27.07	0.21	3000	-10	1.31	0.15
14	21	28.45	5.44	0.17	37.88	0.40	3500	30	4.81	0.16	27.07	0.18	3000	-4	1.15	0.05
14	21	33.13	5.13	0.15	37.79	0.63	3500	51	4.55	0.17	27.07	0.16	3000	4	1.07	0.04
14	21	42.52	4.56	0.13	36.39	0.24	3500	21	3.99	0.12	26.99	0.07	3000	10	0.90	0.03
14	21	48.38	4.25	0.15	131.57	96.26	3500	22	3.68	0.13	27.21	0.30	3000	21	6.27	5.49
14	21	51.89	4.06	0.18	34.72	-0.02	3500	37	3.49	0.12	26.64	-0.27	3000	24	0.78	0.06

76-6-D2-3

FIGURE D2-2. SAMPLE LISTING OF MERGED ARTS III AND THEODOLITE DATA

ERROR PARAMETER ESTIMATION.

Based on the information contained in the ANA-140 study wherein ARTS III and EAIR were compared (appendix D1), there is no significant linear relationship between the range and azimuth error values and the distance of the aircraft from/to the ASR-5. Therefore, the error values within each data group were lumped together, and maximum-likelihood estimates were computed.

RANGE ERROR ESTIMATES. Estimates of the mean and standard deviation (variability) of the range errors for each of the error data groups are shown in table D2-2. Minus values of mean range error indicate that the ARTS III reported data were, on the average, less, or closer to the ASR-5, than that recorded by the Theodolites. Conversely, plus mean values indicate that ARTS III measurements were, on the average, greater, or further from the ASR-5, than those of the Theodolites. To determine if some of the data could be combined to obtain better overall estimates of range accuracy, tests of homogeneity were performed, and where allowable, combined estimates were computed.

a. Pooled Standard Deviations. The statistical test procedures shown in appendix C3 were applied to determine if the standard deviations estimated for each azimuth and beacon code could be assumed to be from the same normal distribution. Classification was by flight direction, radar condition, and test date. In each case, the standard deviations can be assumed to be from the same normal distributions. Therefore, pooled standard deviations were computed as shown in table D2-3.

In addition, the range of errors based on the 3-sigma limits is given. The range of ± 3-sigma, or 6 sigma, infers that at least 99 percent of the errors can be expected to be within the range derived.

b. Grand Means. The statistical test procedures shown in appendix C4 were used to determine if the means estimated for azimuth and beacon code could be assumed to be from the same normal distribution. For both azimuth and beacon code, significant differences were determined at the .01 significance level. Therefore, these data could not be combined.

AZIMUTH ERROR ESTIMATES. Estimates of the mean and standard deviation (variability) of the azimuth errors for each of the error data groups are shown in table D2-4. Plus mean values indicate that the ARTS III reported data were, on the average, greater, or more clockwise, than that reported by the Theodolites. Again, tests of homogeneity were performed to determine if some of the data could be combined to provide a more precise estimate of azimuth accuracy. Combined estimates are shown in table D2-4.

a. Pooled Standard Deviations. The statistical test procedures used previously for the range error standard deviations were applied to the azimuth error standard deviations. Pooled standard deviations are shown in table D2-5. In some cases, all of the standard deviations were pooled, and in others, most of the values were combined. In two cases, however, only the 1211 beacon

TABLE D2-2. RANGE ERROR ESTIMATES[1]

Azimuth	Test Date	Beacon Code	Inbound Beacon-Only N	Inbound Beacon-Only $\bar{X}$ (nmi)	Inbound Beacon-Only S (nmi)	Inbound Merged N	Inbound Merged $\bar{X}$ (nmi)	Inbound Merged S (nmi)	Outbound Beacon-Only N	Outbound Beacon-Only $\bar{X}$ (nmi)	Outbound Beacon-Only S (nmi)	Outbound Merged N	Outbound Merged $\bar{X}$ (nmi)	Outbound Merged S (nmi)
300° -320°	11/6/74	1211	4	-0.070	0.024	7	-0.099	0.020	18	-0.045	0.023	9	-0.082	0.020
		0722	-	-	-	-	-	-	6	.002	.027	11	-0.37	.026
	11/8/74	1211	14	.071	.025	13	- .065	.030	17	.193	.020	9	.061	.033
		0722	11	.121	.018	6	.012	.034	13	.231	.026	13	.103	.031
200° -220°	11/6/74	1211	12	- .060	.010	3	- .077	.021	7	- .059	.016	-	-	-
		0722	8	- .009	.021	11	- .023	.028	11	- .005	.020	-	-	-
	11/8/74	1211	22	.089	.028	6	- .040	.036	25	.166	.033	3	.037	.032
		0722	17	.142	.030	15	.042	.040	25	.225	.025	-	-	-
20° - 40°	11/6/74	1211	12	- .059	.017	4	- .063	.031	19	- .025	.025	8	- .039	.017
		0722	4	- .038	.009	19	-. 088	.024	12	- .027	.021	15	- .059	.025
	11/8/74	1211	26	.097	.022	-	-	-	15	.191	.028	12	.062	.027
		0722	20	.094	.030	3	- .033	.015	13	.191	.027	10	.056	.032
100° - 120°	11/6/74	1211	11	- .019	.022	5	.000	.025	13	.004	.023	4	.018	.017
		0722	-	-	-	8	- .094	.036	8	- .044	.021	-	-	-
	11/8/74	1211	3	.107	.015	20	.034	.033	16	.241	.029	-	-	-
		0722	8	.091	.020	18	- .035	.027	18	.179	.028	6	.053	.041

[1] ARTS III target reports minus Theodolites from 3 to 10 nmi from the ASR-5.

Legend: N - Sample Size
$\bar{X}$ - Mean
S - Standard Deviation

Formulas: $\bar{X} = \frac{\Sigma X}{N}$ $S = \sqrt{\frac{\Sigma (X - \bar{X})^2}{N - 1}}$

TABLE D2-3. COMBINED RANGE ERROR ESTIMATES[1]

Flight Direction	Radar Condition	Test Date	Pooled Standard Deviation[2] S_p (nmi)	Range[3] $\bar{X} \pm 3S_p = 6S_p$ (nmi)
Inbound	Beacon-Only	11/6/74	0.018 N=51	0.108
		11/8/74	.026 N=120	.156
	Merged	11/6/74	.026 N=57	.156
		11/8/74	.033 N=81	.198
Outbound	Beacon-Only	11/6/74	.023 N=94	.138
		11/8/74	.027 N=142	.162
	Merged	11/6/74	.022 N=47	.132
		11/8/74	.032 N=53	.192

[1]Standard deviations tested at the .01 level of significance.

[2]All sample estimates were pooled.

[3]At least 99 percent of the range errors can be expected to fall within this range.

Legend: N - Sample Size

Formula $$S_p = \sqrt{\frac{(N_1-1)S_1^2 + \ldots + (N_k-1)S_k^2}{N_1 + N_2 + \ldots + N_k - k}}$$

TABLE D2-4. AZIMUTH ERROR ESTIMATES[1]

Azimuth	Test Date	Beacon Code	Inbound Beacon-Only N	Inbound Beacon-Only $\overline{X}$ (deg)	Inbound Beacon-Only S (deg)	Inbound Merged N	Inbound Merged $\overline{X}$ (deg)	Inbound Merged S (deg)	Outbound Beacon-Only N	Outbound Beacon-Only $\overline{X}$ (deg)	Outbound Beacon-Only S (deg)	Outbound Merged N	Outbound Merged $\overline{X}$ (deg)	Outbound Merged S (deg)
300° - 320°	11/6/74	1211	4	0.54	0.355	7	0.78	0.283	17	0.56	0.184	9	0.47	0.206
		0722	-	-	-	-	-	-	6	.78	.392	11	.68	.252
	11/8/74	1211	14	1.17	.206	14	1.22	.143	16	1.04	.077	9	.95	.076
		0722	11	1.14	.232	5	.97	.091	12	.87	.241	13	.84	.182
200° - 220°	11/6/74	1211	12	.75	.236	3	.66	.031	6	.37	.148	-	-	-
		0722	8	.54	.609	11	.43	.169	11	.64	.202	-	-	-
	11/8/74	1211	20	1.29	.162	6	1.18	.130	25	.95	.113	3	.92	.042
		0722	16	.91	.202	14	.80	.207	25	1.25	.151	-	-	-
20° - 40°	11/6/74	1211	12	.31	.226	4	.51	.040	19	.70	.377	8	.65	.117
		0722	5	.92	.686	19	.79	.223	11	.43	.286	15	.53	.160
	11/8/74	1211	25	.99	.301	-	-	-	14	1.17	.186	12	1.09	.230
		0722	19	1.35	.265	3	1.29	.141	13	.90	.119	10	.81	.183
100° - 120°	11/6/74	1211	11	.86	.250	5	.79	.132	12	.46	.156	4	.67	.267
		0722	-	-	-	8	.50	.077	9	.59	.112	-	-	-
	11/8/74	1211	3	1.29	.397	19	1.14	.111	15	1.21	.115	-	-	-
		0722	8	1.04	.504	18	.85	.117	18	1.20	.353	6	1.07	.298

[1]ARTS III target reports minus Theodolites from 3 to 10 nmi from the ASR-5.

Legend: N ~ Sample Size
$\overline{X}$ ~ Mean
S ~ Standard Deviation

Formulas: $\overline{X} = \frac{\Sigma X}{N}$ $\qquad S = \sqrt{\frac{\Sigma (X-\overline{X})^2}{N-1}}$

TABLE D2-5. COMBINED AZIMUTH ERROR ESTIMATES

Flight Direction	Radar Condition	Test Date	Pooled Standard Deviation S_p (degrees)	Range[2] $\bar{X} \pm 3S_p = 6S_p$ (degrees)
Inbound	Beacon-Only	11/6/74	0.249[3] N=39	1.49
		11/8/74	.268[4] N=116	1.61
	Merged	11/6/74	.180[4] N=57	1.08
		11/8/74	.141[4] N=79	.85
Outbound	Beacon-Only	11/6/74	.216[5] N=70	1.30
		11/8/74	.145[6] N=120	87
	Merged	11/6/74	.190[3] N=21	1.14
		11/8/74	.210[7] N=29	1.26

[1] Standard deviations tested at the .01 level of significance.

[2] At least 99 percent of the azimuth errors can be expected to fall within this range.

[3] Only the "1211" standard deviations were pooled.

[4] All sample estimates were pooled.

[5] Does not include the "1211/30°" standard deviation.

[6] Does not include the "0722/110°" standard deviation.

[7] Only the "0722" standard deviations were pooled.

Legend: N - Sample Size

Formula: $$S_p = \sqrt{\frac{(N_1-1)S_1^2+\ldots+(N_k-1)S_k^2}{N_1+N_2+\ldots+N_k-k}}$$

code standard deviations could be pooled, and in one other case, only the 0722 beacon code standard deviations were pooled. Table D2-5 also contains the ranges within which at least 99 percent of the azimuth errors can be expected to lie.

b. Grand Means. Using the statistical procedures referenced above for the range errors, the means of the azimuth errors were compared. As in the case of the range errors, significant differences were determined at the .01 significance level for both azimuth and beacon code. Therefore, grand means for combined means were not computed.

COMPARISON TESTING.

Based on the statistical test procedures described in appendix D1F, the range and azimuth error pooled standard deviations given in tables D2-3 and D2-5, respectively, were compared (using Wang 700C/701 computer programs) to determine the effects of flight direction and radar condition. The results of these analyses are shown in table D2-6. Due to the absence of sufficient mean error data, the range and azimuth mean errors were not statistically compared. Visual comparisons of the means from tables D2-2 and D2-4 were made, however.

INBOUND VERSUS OUTBOUND.

a. Range Error. Table D2-6 indicates that there is no significant difference between the inbound and outbound error variability for both the "beacon-only" and "merged" conditions. Table D2-2 does indicate that the "inbound" means were always less or more negative than the "outbound" means, regardless of the radar condition.

b. Azimuth Error. The one case tested (November 8, 1974, beacon-only) indicates that there was a significant difference in the "inbound" and "outbound" azimuth error variability. Table D2-4 indicates that most of the "inbound" standard deviations are greater than those for "outbound." Table D2-4 also indicates that the "inbound" means were generally higher or more clockwise than the "outbound" means, regardless of the radar condition.

BEACON-ONLY VERSUS MERGED.

a. Range Error. Table D2-6 indicates that there is generally no significant difference between the "beacon-only" reports and "merged" reports variability. Table D2-2 does indicate that the "beacon-only" means were almost always greater or more positive than the "merged" means, regardless of the flight direction.

b. Azimuth Error. The one case tested (November 8, 1974, "inbound") indicates that there is a significant difference in the "beacon-only" and "merged" azimuth error variability. Table D2-4 indicates that most of the "beacon-only" standard deviations are greater than those for "merged". Table D2-4 also indicates that the "beacon-only" means were generally higher or more clockwise than the "merged" means, regardless of the flight direction.

TABLE D2-6. RESULTS OF STANDARD DEVIATION COMPARISON TESTS

Error	Test Date	Inbound vs Outbound		Beacon-Only vs Merged	
		Beacon-Only	Merged	Inbound	Outbound
Range	11/6/74	No Significance (.05)	No Significance (.05)	Significance (.01)	No Significance (.05)
	11/8/74	No Significance (.05)	No Significance (.05)	No Significance (.01)	No Significance (.05)
Azimuth	11/6/74	Note 1	Note 1	Note 1	Note 1
	11/8/74	Significance[2] (.01)	Note 1	Significance (.01)	Note 1

[1]In cases where only a single beacon code was involved, standard deviations were not compared.

[2]The "outbound-beacon-only" pooled standard deviation used in the analysis did not contain any "0722/110°" data.

Legend: ( ) - Level of Significance.

SUMMARY OF RESULTS.

Based on the Theodolite data contained in this report, the ANA-140 Technical Bulletin dated May 1975, where EAIR data was compared, and the Mitre Report dated May 28, 1975, which used both SAFI and EAIR data, the following ARTS III (RBTL) target report accuracies can be expected under good beacon signal conditions:

1. RANGE ACCURACY. Table D2-7 shows the range error mean and standard deviation estimates associated with the three independent studies mentioned above. The table indicates that there is general agreement between the error estimates. Generally, the mean errors were within ±0.1 nmi, with standard deviations between 0.02 and 0.03 nmi. In addition, at least 99 percent of the individual range errors can be expected to vary less than approximately 0.16 nmi (1,000 feet) or within 500 feet of the mean error.

The mean errors were affected by both radar condition and flight direction. "Beacon-only" means can be expected to be less (more negative) than the "merged" means. "Inbound" means can be expected to be less (more negative) than the "outbound" means.

Range error variability, based primarily on the ANA-140 study where EAIR was used, seems to be independent of flight direction, but may be slightly less under "merged" conditions than "beacon-only" conditions. The EAIR analysis is considered to be the most accurate of the three analyses due to the comprehensiveness of the data collected and the fact that the EAIR measurement variability remains constant throughout the flights.

2. AZIMUTH ACCURACY. Table D2-8 shows the azimuth error mean and standard deviation estimates associated with the three studies. Again, there seems to be general agreements between the results. Generally, the mean errors were within 0.5° and 1.3°, with standard deviations between 0.15° and 0.25°. In addition, at least 99 percent of the individual azimuth errors can be expected to vary less than approximately 1° or within 0.5° of the mean error.

The mean errors were affected by both radar condition and flight direction. "Beacon-only" means can be expected to be higher (more clockwise) than the "merged" means. "Inbound" means can be expected to be higher (more clockwise) than the "outbound" means.

Azimuth error variability based primarily on the ANA-140 study seems to be independent of flight direction and radar condition.

TABLE D2-7. SUMMARY OF RANGE ERROR ESTIMATES (nmi)

Flight Direction	Radar Condition	Min/Max Mean[1]		Standard Deviation[2] (S_p)		Range[3] ($6S_p$)	
		EAIR	Theodolites	EAIR	Theodolites	EAIR	Theodolites
Inbound	Beacon-Only	-0.06/0.10	-0.07/0.14	0.027	0.018/0.26	0.162	0.108/0.156
	Merged	-.10/-.03	-.10/.04	.023	.026/.033	.138	.156/.198
Outbound	Beacon-Only	-.04/.21	-.06/.24	.028	.023/.027	.168	.138/.162
	Merged	-.07/.08	-.08/.10	.016	.022/.032	.096	.132/.192

[1]SAFI Test Results = -.06 (SAFI)/ -.05 (EAIR)

[2]SAFI Test Results = .044 (SAFI)/ .03 (EAIR)

[3]SAFI Test Results = .264 (SAFI)/ .13 (EAIR)

[4]11/6/74 and 11/8/74 data

TABLE D2-8. SUMMARY OF AZIMUTH ERROR ESTIMATES (Degrees)

Flight Direction	Radar Condition	Min/Max Mean[1]		Standard Deviation[2] (S_p)		Range[3] ($6S_p$)	
		EAIR (degrees)	Theodolites (degrees)	EAIR (degrees)	Theodolites[4] (degrees)	EAIR (degrees)	Theodolites[4] (degrees)
Inbound	Beacon-Only	1.05/1.25	0.31/1.35	0.176	0.249/0.268	1.06	1.49/1.61
	Merged	.93/1.04	.43/1.29	.151	.180/.141	.91	1.08/.85
Outbound	Beacon-Only	.88/1.17	.37/1.25	.191	.216/.145	1.15	1.30/.87
	Merged	.79/1.02	.47/1.09	.154	.190/.210	.92	1.14/1.26

[1]SAFI Test Results = 1.33 (SAFI)/1.18 (EAIR)

[2]SAFI Test Results = .232 (SAFI)/.230 (EAIR)

[3]SAFI Test Results = 1.39 (SAFI)/1.38 (EAIR)

[4]11/6/74 and 11/8/74 data

APPENDIX D3

ARTS III (RBTL) REPORT/TRACK ACCURACY
by John J. Wojciech, ANA-140 (June, 1975)

1. On December 4, 1974, NAFEC aircraft, N377, flew several radial flights between 120° and 140° about 10 to 40 nmi from the ASR-5. Both ARTS III RBTL target report and tracking message data were extracted as shown in figure B-2. These data were then compared to corresponding EAIR data as shown in figure 9. It should be noted that each of the target reports was based on good quality beacon (mode 3/A and C validities=3) and that each of the tracking messages was also of high quality (firmness=39).

2. The target report errors were broken down by flight direction (inbound/outbound) and radar condition (beacon-only/merged). The tracking message values were subdivided by flight direction. Each group of errors was checked for "outliers" and the distribution of the errors was found to be generally normal. The mean and standard deviations associated with each error group are shown in table D3-1. A minus mean error in range indicates that ARTS measured, on the average, less than EAIR. A plus mean error in azimuth indicates that ARTS read, on the average, more clockwise.

3. Target report and tracking message accuracy were compared statistically using the parameter estimates given in table D3-1. The results of these comparison tests, shown in table D3-2, indicate that range error variability is less using the target report data; however, there do not seem to be any obvious differences in the means of the range errors. In the case of the azimuth data, there do not seem to be any real differences in either the error means or the standard deviations of the errors.

Table D3-1 Target Report and Tracking Message Error Estimates [1]

Error	Flight Direction	Target Report						Tracking Message		
		Merged			Beacon-Only					
		N	$\bar{X}$	S	N	$\bar{X}$	S	N	$\bar{X}$	S
Range (nmi)	Inbound	30	-.099	.019	32	-.061	.028	32	-.113	.053
	Outbound	37	-.067	.012	31	-.038	.030	30	-.056	.035
Azimuth (Deg.)	Inbound	30	.93	.139	32	1.05	.139	32	.90	.138
	Outbound	37	.88	.120	31	.97	.144	30	.86	.134

[1] ARTS III target reports/tracking messages minus EAIR from 10 to 40 nmi from the ASR-5.

Legend: N - Sample size
$\bar{X}$ - Mean
S - Standard Deviation

Formulas: $\bar{X} = \frac{\Sigma X}{N}$

$$S = \sqrt{\frac{\Sigma (X - \bar{X})^2}{N - 1}}$$

Table D3-2. Results of Comparison Tests[1]

Error	Parameter	Target Report vs. Tracking Message			
		Inbound		Outbound	
		Merged	Beacon-Only	Merged	Beacon-Only
Range	Standard Deviation	Significant (.01)	Significant (.01)	Significant (.01)	Not Significant (.05)
	Mean	Not Significant (.05)	Significant (.01)	Not Significant (.05)	Not Significant (.01)
Azimuth	Standard Deviation	Not Significant (.05)	Not Significant (.05)	Not Significant (.05)	Not Significant (.05)
	Mean	Not Significant (.05)	Significant (.01)	Not Significant (.05)	Significant (.01)

[1] Standard deviation comparison test procedures can be found on Page 511 of "Quality Control and Industrial Statistics" by Acheson J. Duncan, Richard D. Irwin, Inc., 1965. Mean comparison procedures can be found on Page 505 of the same text.

Legend: ( ) - Level of Significance.

APPENDIX D4

ARTS III RADAR DISPLAY ERROR ANALYSIS
by John J. Wojciech, ANA-140 (January 1975)

SUMMARY.

A test was conducted at the National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, New Jersey, to determine the ARTS III digital symbol position error. Data were collected in all four quadrants and over most of the 11-inch display radius. The NAFEC Telereadex Film Reader was used to measure the position of the digital symbol from scope photographs. These target positions were compared to those generated by the ARTS III to determine the display errors both in range and azimuth.

The range and azimuth errors were showed to be definitely correlated with the distance of the symbol from the display center. Based on a simple linear regression analysis, the mean range and azimuth errors can be expected to fall within ± 0.15 nmi. Individual range and azimuth errors can be expected to fall within ± 0.25 nmi, 95 percent of the time.

The report shows that these display errors become insignificant compared to the reading errors that are possible using the human eye as the display range setting is increased beyond 30 nmi.

INTRODUCTION

PURPOSE.

This technical bulletin describes the analysis performed at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey, to determine the range and azimuth errors of an ARTS III radar display.

BACKGROUND.

The Systems and Equipment Engineering Branch, ANA-140, has been tasked to investigate the errors associated with an ARTS III Terminal Radar System, Subprogram No. 142-177. This system consists of three major parts; the airport surveillance radar (ASR) with associated beacon, the ARTS III, and the radar display. The analysis contained herein deals with the RBTL configuration radar display error component of the system error and is defined as the difference between the position of a target as determined by ARTS III and the position of the digital symbol representing that target on the display.

The ARTS III determines the range and azimuth of a target and records this information on magnetic tape (UNISERVO V1c system). Simultaneously, the x and y coordinates of the target are sent to the radar display. This digital data are then converted to analog signals and are displayed on the cathode ray tube (CRT). There is approximately a 1-second delay between the time the target is reported and the time the digital symbol is positioned. This time is required in the event a radar target is not received and a predicted target generated by the software has to be displayed.

DISCUSSION

TEST CONDITIONS.

DISPLAY. The Type 1 Vertical Display used in the analysis is similar to the one shown in figure D4-1. The CRT is 22 inches in diameter and can display both analog beacon and broadband radar from the ASR, and alphanumeric or digital data generated by the ARTS III. Display ranges can be selected in 1- and 2-nmi increments from 6 nmi to 60 nmi. The specific display and ARTS III system tested are part of the Terminal Automation Test Facility (TATF) at NAFEC.

DISPLAY CALIBRATION. Prior to the test, the radar coordinate positioning accuracy of the display was checked by the UNIVAC maintenance technician in accordance with the procedures recommended for field use. These procedures (ARTS III DAS/DEDS PDFA, Operating Procedures, Section 4.4, 01-2749-A, April 15, 1971) indicate that adjustments are only required if the difference between the actual position of the center of the displayed digital symbol and the computer-generated position exceeds 0.125 nmi. This check is done visually at the 12-nmi range setting using range marks of 2 nmi and a symbol size of

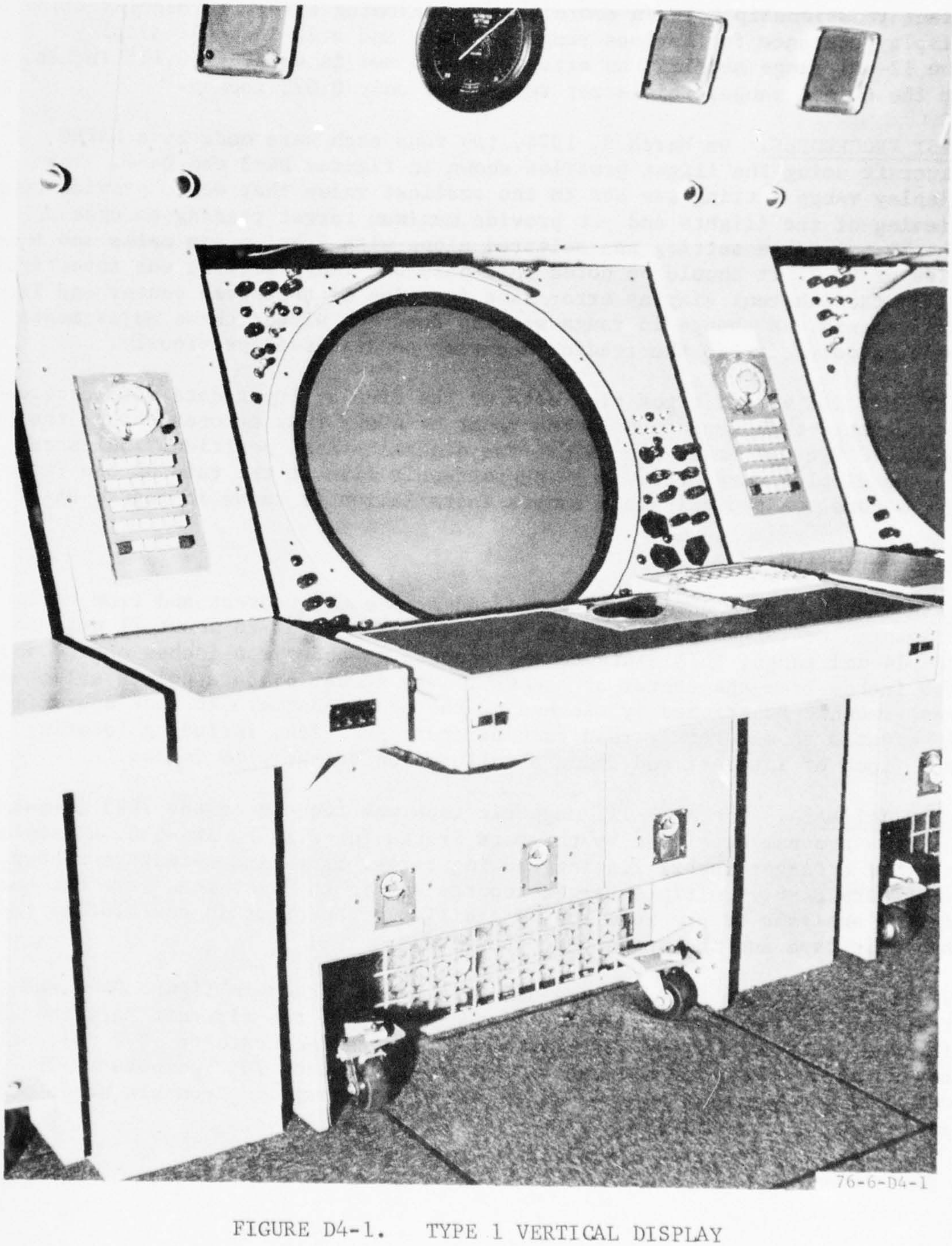


FIGURE D4-1.   TYPE 1 VERTICAL DISPLAY

"2". This smaller range is selected because it is extremely difficult to visually distinguish 0.125 nmi at the larger ranges. Figure D4-2 shows the exact relationship between coordinate positioning error or "display error" and display distance for various range settings and a 22-inch CRT display. At the 12-nmi range setting, an error of 0.125 nmi is equal to 0.114 inches, while at the 60-nmi range, this error represents only 0.023 inches.

TEST PROCEDURES. On March 8, 1974, two runs each were made by a NAFEC aircraft using the flight profiles shown in figures D4-3 and D4-4. The display range setting was set to the smallest value that would provide complete viewing of the flights and yet provide maximum target reading accuracy. The 14-nmi range setting was selected along with 2-nmi range marks and a symbol size of "2." It should be noted that only one range setting was investigated, since the inherent display error is a function of the sweep center and linearity adjustments. A change in range setting does not affect these adjustments. Range setting only affects the reading accuracy as discussed previously.

The ARTS III aircraft position data or the display input data were recorded on magnetic tape each scan of the radar or every four seconds using the UNISERVO Vlc system at the TATF. The digital symbol positions indicated on the display were recorded on photographic film at the rate of one frame per second. A typical scope camera installation is shown in figure D4-5.

DATA REDUCTION.

DATA SAMPLE. Data points were selected from each quadrant and from various distances or ranges from the ASR from about 3 nmi out to about 11 nmi. At the 14-nmi range, this distance corresponds to about 2.5 inches out to about 8.5 inches from the center of the CRT. The number of data points selected was somewhat restricted by the use of the scope photos. It took approximately 10 minutes to accurately read each aircraft position, including locating the frame of interest and doing a calibration of the film reader.

ARTS III DATA. The ARTS III magnetic tape was reduced on the 7090 computer using a program developed by the Data Processing Branch, ANA-550. A sample copy of a target report listing showing target range and azimuth is shown in figure D4-6. Multiple target reports within the same scan were not used in the analysis to preclude the possibility of an error in correlating the magnetic tape and the scope photo targets.

SCOPE PHOTOS. The NAFEC Telereadex Film Reader shown in figure D4-7 was used to determine the x-y coordinates of the center of the aircraft targets selected for the analysis. These coordinates, considered accurate to $\pm$0.2 nmi, were converted to range and azimuth values using the Wang 700C computer. The detailed procedures used to measure the target position from the scope photos are given in appendix D4A.

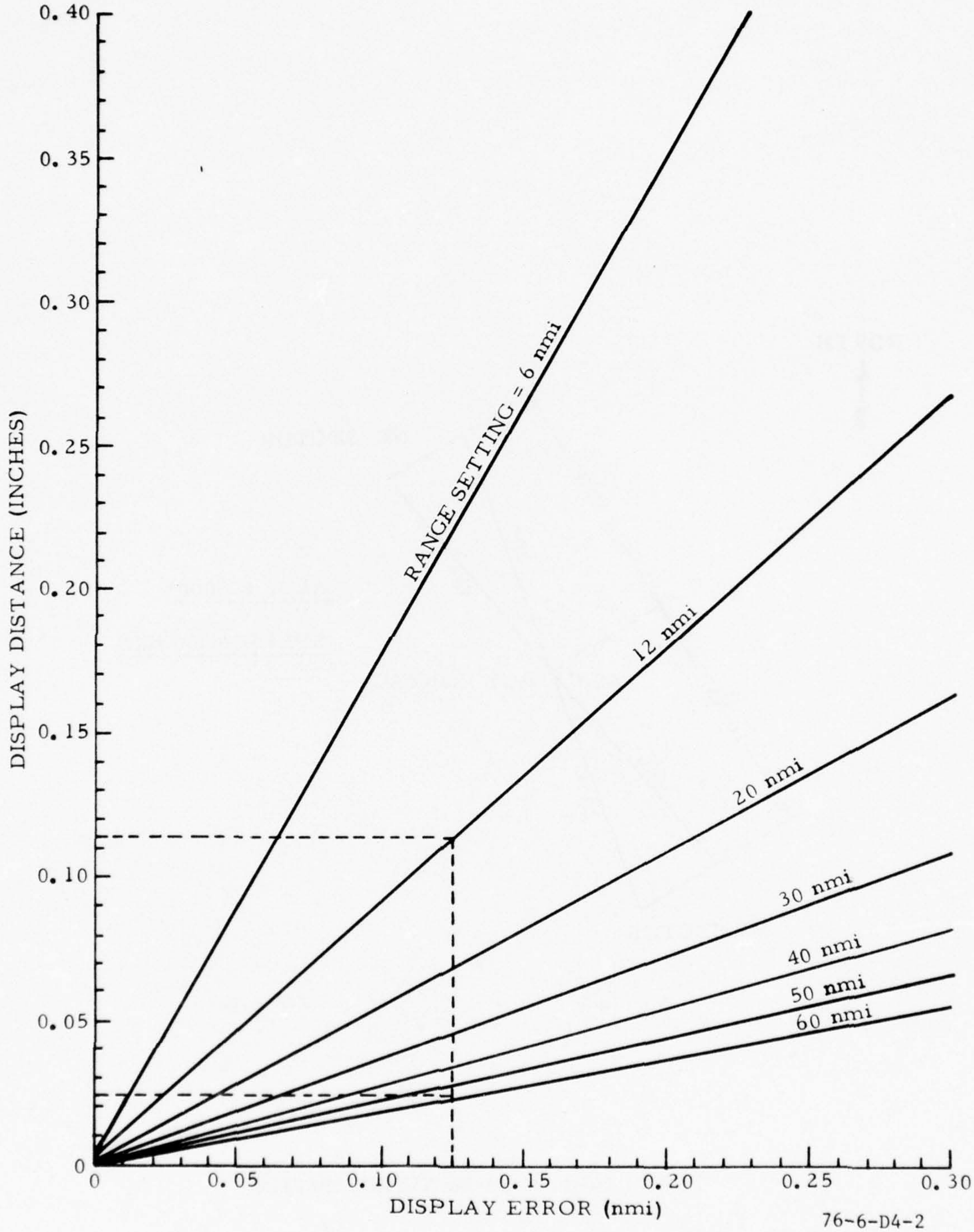


FIGURE D4-2 NOMOGRAPH OF DISPLAY ERROR VERSUS DISPLAY DISTANCE FOR VARIOUS DISPLAY RANGE SETTINGS (22-INCH CRT)

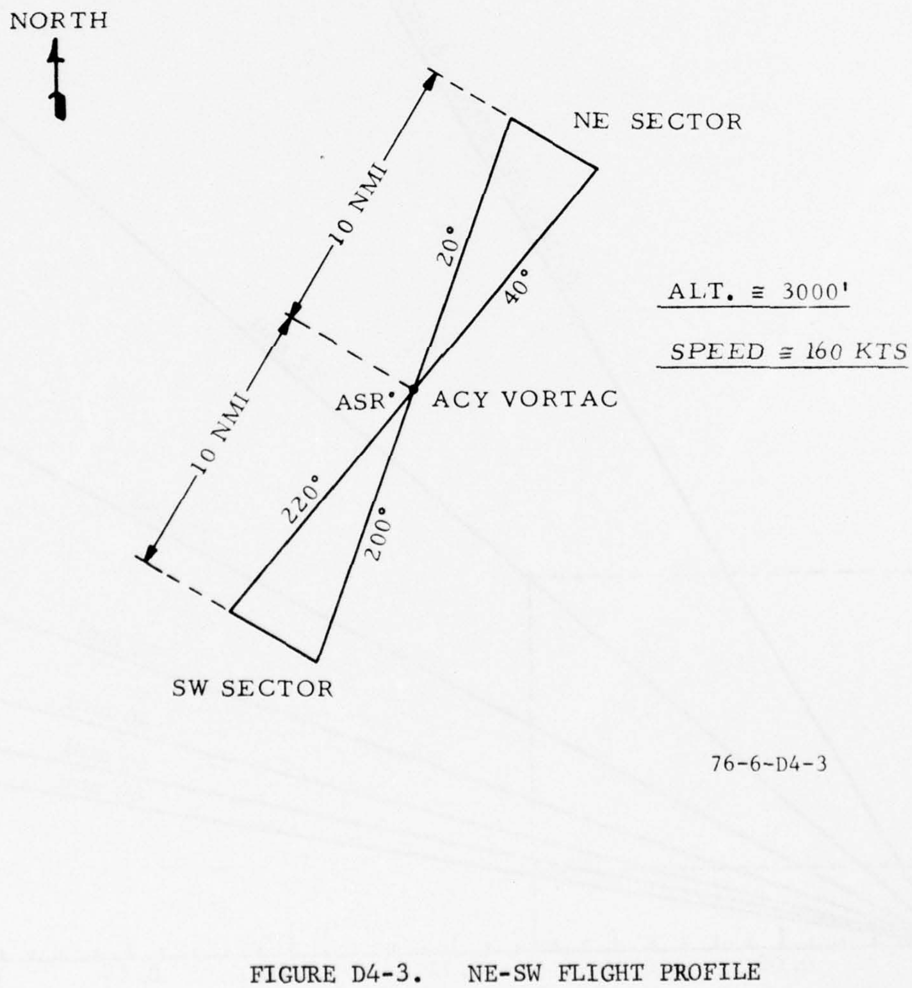


FIGURE D4-3. NE-SW FLIGHT PROFILE

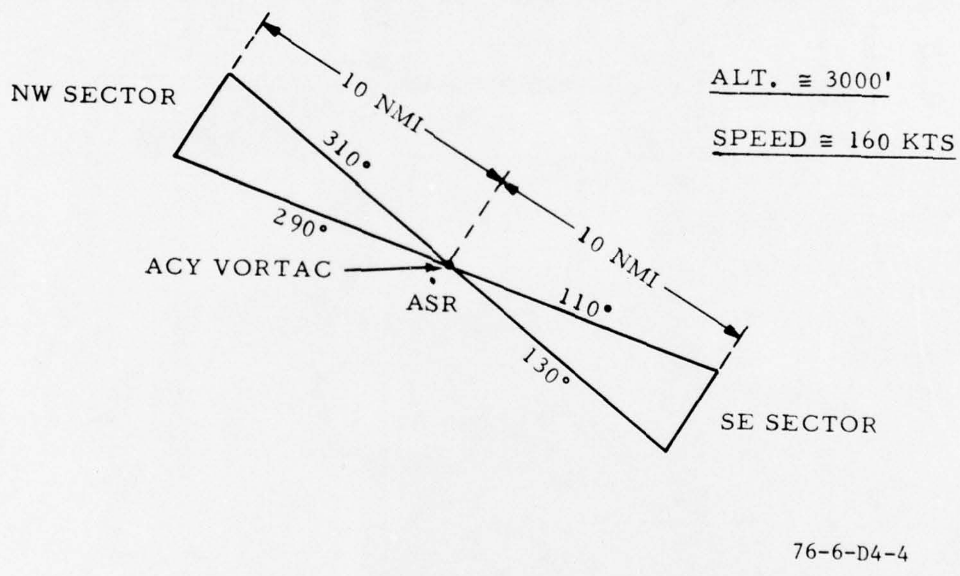


FIGURE D4-4. NW-SE FLIGHT PROFILE

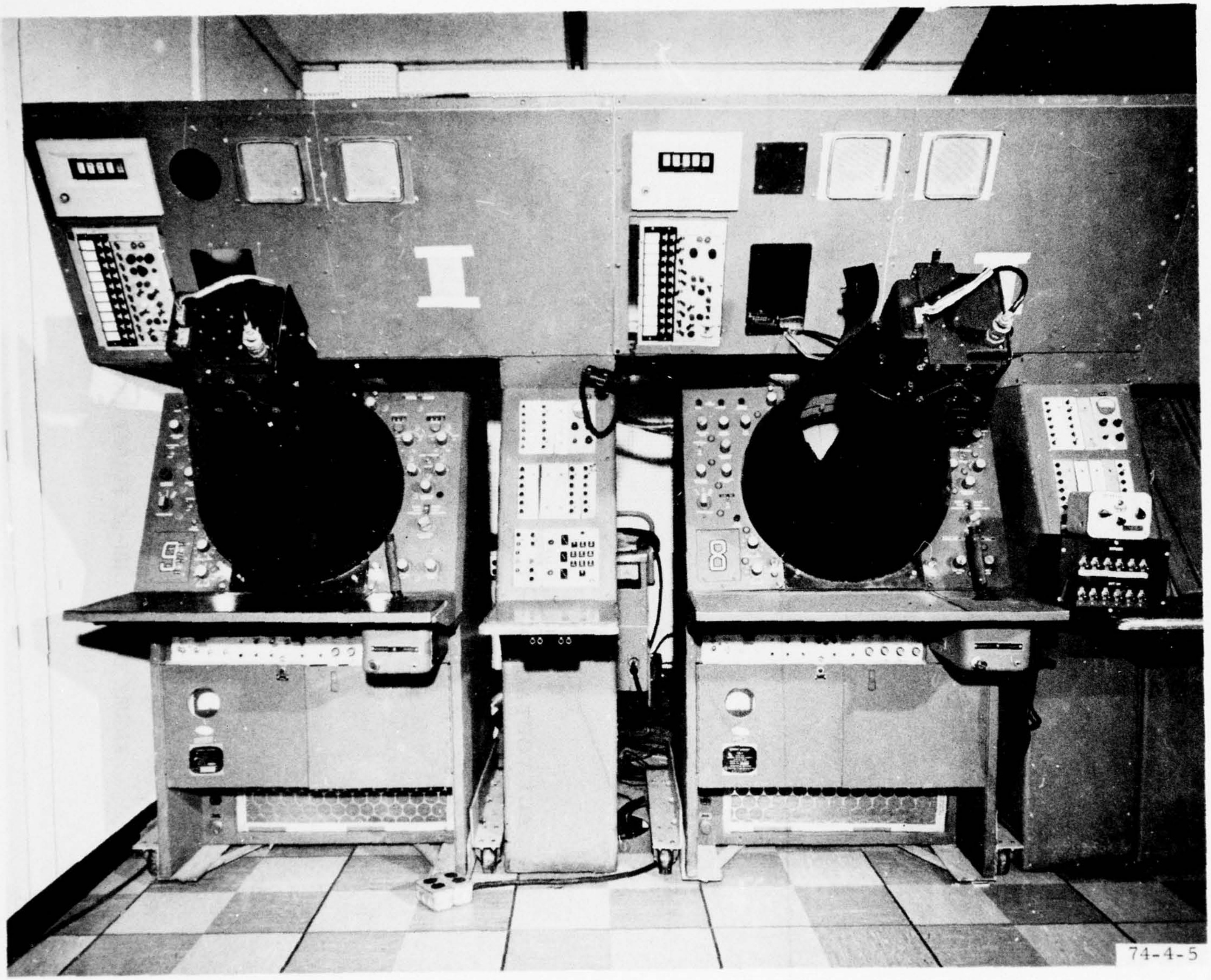


FIGURE D4-5. RADAR DISPLAYS WITH CAMERA INSTALLATIONS

ARTS III TEST   DATA TAKEN 05 MAY -74   B-101   FILE 1   RUN 1

HR	MN	TIME SEC	RANGE NM	AZIM DEG	ALT FT	BEACON CODE	EMER FLAG	RADIO FAIL	SPI 3/A	W/S	3/A VALID	3/C VALID	MESG CODE
14	22	23.89	3.250	319.807	5500	1211	0	0	0	0	3	2	2
14	22	25.12	3.312	72.570	5500	1211	0	0	0	1	3	3	2
14	22	31.14	3.625	266.896	5500	1211	0	0	0	0	3	3	2
14	22	32.62	3.750	39.963	5500	1211	0	0	0	1	1	3	2
14	22	32.73	3.687	45.324	5500	1211	0	0	0	0	3	2	2
14	22	35.20	3.875	270.852	5500	1211	0	0	0	1	3	3	2
14	22	35.20	3.875	276.125	5500	1211	0	0	0	0	3	2	2
14	22	35.56	3.875	307.062	5500	1211	0	0	0	0	1	3	2
14	22	35.69	3.937	313.303	0	1211	0	0	0	0	3	0	2
14	22	36.43	3.937	23.703	150500	1211	0	0	0	0	3	2	2
14	22	42.57	4.375	232.355	5500	1211	0	0	0	0	3	3	2
14	22	42.94	4.375	265.578	5500	1211	0	0	0	1	3	3	2
14	22	46.88	4.562	263.820	5500	1211	0	0	0	0	3	3	2
14	22	50.92	4.875	269.973	5500	1211	0	0	0	0	3	3	2
14	22	52.65	5.000	74.768	5500	1211	0	0	0	0	3	3	2
14	22	54.86	5.062	275.246	5600	1211	0	0	0	0	3	3	2
14	22	55.96	5.125	19.045	5600	1211	0	0	0	1	3	3	2
14	22	58.91	5.312	284.650	5600	1211	0	0	0	1	3	2	2
14	22	59.03	5.312	295.637	5600	1211	0	0	0	0	3	3	2
14	22	59.16	5.312	313.303	5600	1211	0	0	0	0	3	2	2
14	22	59.89	5.375	16.848	5600	1211	0	0	0	1	3	2	2
14	23	0.02	5.375	25.549	5600	1211	0	0	0	1	3	3	2
14	23	2.47	5.500	256.789	150100	1211	0	0	0	1	1	3	2
14	23	2.84	5.562	284.650	5600	1211	0	0	0	0	3	3	2
14	23	2.96	5.562	292.121	5600	1211	0	0	0	0	3	3	2
14	23	5.05	5.750	127.326	4900	1211	0	0	0	0	1	3	2
14	23	6.40	5.812	251.516	5600	1211	0	0	0	1	3	3	2
14	23	6.40	5.750	257.141	4900	1211	0	0	0	1	3	2	2
14	23	6.52	5.812	262.238	5600	1211	0	0	0	1	3	3	2
14	23	14.27	6.312	254.768	5600	1211	0	0	0	0	3	3	2
14	23	20.79	6.750	128.557	5700	1211	0	0	0	0	3	3	2
14	23	26.07	7.062	254.592	5500	1211	0	0	0	1	3	3	2
14	23	28.77	7.250	144.113	5500	1211	0	0	0	1	3	3	2
14	23	30.00	7.312	254.680	5500	1211	0	0	0	0	3	3	2
14	23	33.94	7.562	254.768	5500	1211	0	0	0	1	3	3	2
14	23	37.88	7.812	255.119	5500	1211	0	0	0	1	3	3	2
14	23	38.00	7.812	261.887	5500	1211	0	0	0	0	3	2	2
14	23	38.37	7.875	294.582	5500	1211	0	0	0	1	3	3	2
14	23	41.81	8.062	252.482	5500	1211	0	0	0	0	3	3	2
14	23	49.68	8.562	252.307	5500	1211	0	0	0	1	1	3	2
14	23	53.62	8.812	248.176	5500	1211	0	0	0	0	3	3	2
14	23	57.55	9.125	249.934	5600	1211	0	0	0	0	3	3	2
14	24	1.49	9.375	251.252	5500	1211	0	0	0	1	3	3	2
14	24	5.44	9.562	251.164	5500	1211	0	0	0	1	3	3	2
14	24	9.37	9.875	250.285	0	1211	0	0	0	0	3	0	2
14	24	13.30	10.125	248.967	5500	1211	0	0	0	0	3	3	2
14	24	17.23	10.375	250.021	5500	1211	0	0	0	1	3	3	2
14	24	17.36	10.375	258.811	5500	1211	0	0	0	0	3	2	2
14	24	17.73	10.437	295.812	0	1211	0	0	0	1	3	0	2
14	24	21.17	10.625	248.527	5500	1211	0	0	0	1	3	3	2

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FIGURE D4-6. EXAMPLE OF ARTS III TARGET REPORT LISTING

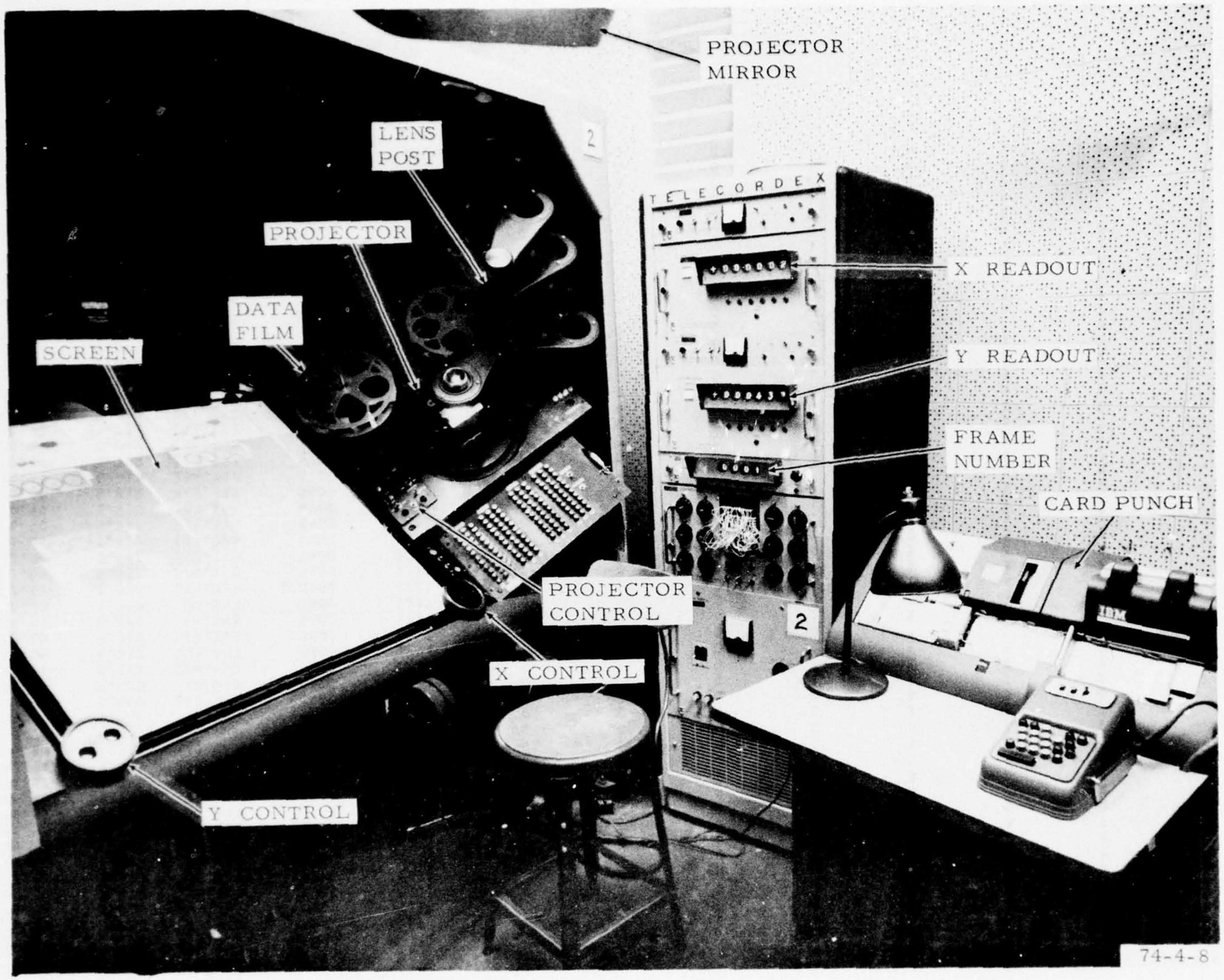

FIGURE D4-7. NAFEC TELEREADEX FILM READER EQUIPMENT

ERROR SUMMARIES.

Tables D4-1 and D4-2 show both the aircraft range and azimuth positions as reported and displayed by the ARTS III for the NE-SW and NW-SE flight profiles, respectively. Also shown are the display errors or the differences resulting in subtracting the reported positions from the displayed positions. The linear offsets associated with the azimuth degree errors are also listed for more direct comparison to the range errors. These error summaries were generated using a Wang 700C/701 computer program developed by ANA-140.

ERROR ANALYSIS.

Since the inherent display errors are independent of the range selected, display error was analyzed as a function of the physical distance of the target from the display center rather than a particular radar range. Therefore, the "displayed" range values given in tables D4-1 and D4-2 were multiplied by the associated CRT scale factor of 11 inches/14-nmi range (full deflection). The range and azimuth errors were grouped into 20°-50°, 115°-130°, 190°-215°, and 285°-315° azimuth sectors with respect to the ASR-4 site. These errors were plotted individually against the distance from the display center, and it was concluded that both range and azimuth error vary linearly with the distance from the display center. Simple linear regression and correlation analyses based on the method of least squares were performed to quantify this relationship. A brief description of these analyses, including the associated assumptions, is given in appendix C1. The analysis results, obtained using a Wang 700C/701 computer program developed by ANA-140, are given as follows:

Range Errors. The $Y=a+bX$ line shown in figure D4-8 for each azimuth sector represents the best estimate of the universe regression line or the linear relationship between range error (Y) and the distance from the display center (X) for distances between 2 inches and 9 inches. It can be noted that the closer the slope of the line (b) is to zero, the less dependent the range error is on the distance from the display center. A negative slope ($b < 0$) indicates that as the distance from the display center increases, the range error increases in the negative direction. A positive slope ($b > 0$) indicates that as the distance from the display center increases, the range error increases in the positive direction. The 95-percent prediction limits, also shown in figure D4-8, indicate for a given distance from the display center, at least 95 percent of the individual range errors can be expected to lie within these limits.

Table D4-3 summarizes the results of the regression and correlation analyses for each azimuth sector. The coefficient of correlation estimates, r, associated with each regression line estimate, represents a measure of the strength of the linear relationship between range error and the distance of the target from the display center, or how well the associated regression line fits the data. Plus or minus values of r between 0.4 and 0.6 are considered indicative of fair to good correlation, while coefficients between 0 and 0.4 indicate little or no correlation and coefficients between 0.6 and 1.0 indicate a high degree of correlation. Table D4-3 shows that for the four azimuth sectors combined, the best estimate of range error between

TABLE D4-1. ARTS III REPORTED VERSUS ARTS III DISPLAYED POSITION (NE-SW)

POSITION 1: ARTS III REPORTED
POSITION 2: ARTS III DISPLAYED
AIRCRAFT ID: 1211

DATE: 3/8/74
RUN NO: 1 & 2

TIME	POSITION 1		POSITION 2		POSITION DIFFERENCE		
	RANGE (NMI)	AZIMUTH (DEGREES)	RANGE (NMI)	AZIMUTH (DEGREES)	RANGE (NMI)	AZIMUTH (DEGREES)	AZIMUTH (NMI)
9 06 48.20	8.50	192.66	8.36	192.57	-.14	-.09	-.01
9 08 02.80	10.81	201.89	10.70	201.55	-.11	-.34	-.06
9 10 12.40	6.94	213.49	6.86	213.11	-.08	-.38	-.05
9 10 59.40	4.75	210.15	4.69	209.79	-.06	-.36	-.03
9 14 06.00	3.56	47.55	3.44	48.53	-.12	.98	.06
9 14 37.40	4.81	46.49	4.74	46.88	-.07	.39	.03
9 15 40.20	7.38	42.89	7.25	43.27	-.13	.38	.05
9 16 35.00	9.63	40.96	9.53	41.47	-.10	.51	.08
9 25 26.40	8.44	192.21	8.31	192.16	-.13	-.05	-.01
9 26 25.40	10.56	201.27	10.41	201.24	-.15	-.03	-.01
9 29 02.40	6.81	213.22	6.71	213.34	-.10	.12	.01
9 30 05.00	4.19	209.00	4.06	208.52	-.13	-.48	-.03
9 32 51.90	3.31	48.60	3.21	49.81	-.10	1.21	.07
9 33 58.60	5.94	44.56	5.88	45.00	-.06	.44	.05
9 34 41.80	7.56	42.28	7.46	43.15	-.10	.87	.11
9 35 24.80	9.25	41.13	9.13	41.58	-.12	.45	.07
9 37 57.60	10.06	19.78	9.92	20.30	-.14	.52	.09
9 38 44.80	7.69	23.91	7.57	24.50	-.12	.59	.08
9 39 24.00	5.56	24.96	5.49	25.91	-.07	.95	.09

TABLE D4-2. ARTS III REPORTED VERSUS ARTS III DISPLAYED POSITION (NW-SE)

POSITION 1: ARTS III REPORTED
POSITION 2: ARTS III DISPLAYED
AIRCRAFT ID: 1211

DATE: 3/8/74
RUN NO: 3&4

TIME	POSITION 1		POSITION 2		POSITION DIFFERENCE		
	RANGE (NMI)	AZIMUTH (DEGREES)	RANGE (NMI)	AZIMUTH (DEGREES)	RANGE (NMI)	AZIMUTH (DEGREES)	AZIMUTH (NMI)
9 51 13.20	8.50	307.71	8.38	307.77	-.12	.06	.01
9 51 52.40	9.94	307.00	9.75	307.38	-.19	.38	.06
9 53 46.00	8.81	288.98	8.63	289.01	-.18	.03	.00
9 54 45.00	6.38	290.13	6.29	289.91	-.09	-.22	-.02
9 55 04.60	5.56	289.86	5.42	289.40	-.14	-.46	-.04
10 01 54.80	11.31	116.90	11.16	116.50	-.15	-.40	-.08
10 03 25.20	9.19	124.19	9.06	123.80	-.13	-.39	-.06
10 04 16.20	6.81	122.34	6.68	122.41	-.13	.07	.01
10 04 47.60	5.31	122.61	5.22	122.41	-.09	-.20	-.02
10 08 17.80	4.81	312.36	4.66	312.31	-.15	-.05	-.00
10 03 41.20	5.88	311.22	5.75	311.62	-.13	.40	.04
10 21 45.00	9.25	124.19	9.10	123.86	-.15	-.33	-.05
10 23 46.80	4.44	129.55	4.35	129.03	-.09	-.52	-.04
10 26 26.00	3.25	316.23	3.15	316.28	-.10	.05	.00
10 26 49.60	4.31	313.68	4.17	314.03	-.14	.35	.03
10 27 24.80	5.94	311.92	5.81	311.79	-.13	-.13	-.01
10 28 08.00	7.88	309.90	7.77	309.94	-.11	.04	.01
10 28 31.60	8.94	310.87	8.82	311.28	-.12	.41	.06
10 30 13.60	10.31	293.56	10.11	294.05	-.20	.49	.09
10 31 20.40	8.00	289.95	7.88	290.05	-.12	.10	.01
10 32 35.00	5.19	291.45	5.03	291.10	-.16	-.35	-.03

TABLE D4-3. RANGE ERROR VERSUS AZIMUTH SECTOR

Azimuth Sector (°)	Estimated Regression Line Y=a+bX (nmi)	Estimated Regression Line Range* (2-9 inches) (nmi)	Estimated 95% Prediction Limit Range** (2-9 inches) (nmi)
20-50 (n=11)	-0.069 - 0.0063X (r=-.44)	-0.08/-0.12	-0.01/-0.20
115-130 (n=6)	-.051 - .0121X (r= -.91)	-.07/-.16	-.03/-.20
190-215 (n=8)	-.065 - .0080X (r= -.49)	-.08/-.14	.01/-.23
285-315 (n=15)	-.093 - .0087X (r= -.45)	-.11/-.17	-.04/-.25

Legend:
X - Distance from center of display
Y - Error that can be expected at X on average
a - Y-Intercept (X=0) of the regression line
b - Slope of the regression line
n - Sample size
r - Coefficient of correlation estimate
* - Y at X=2 inches to Y at X=9 inches
** - A minimum of 95 percent of the errors can be expected to lie within these values over the 2- to 9-inch distance from the display center.

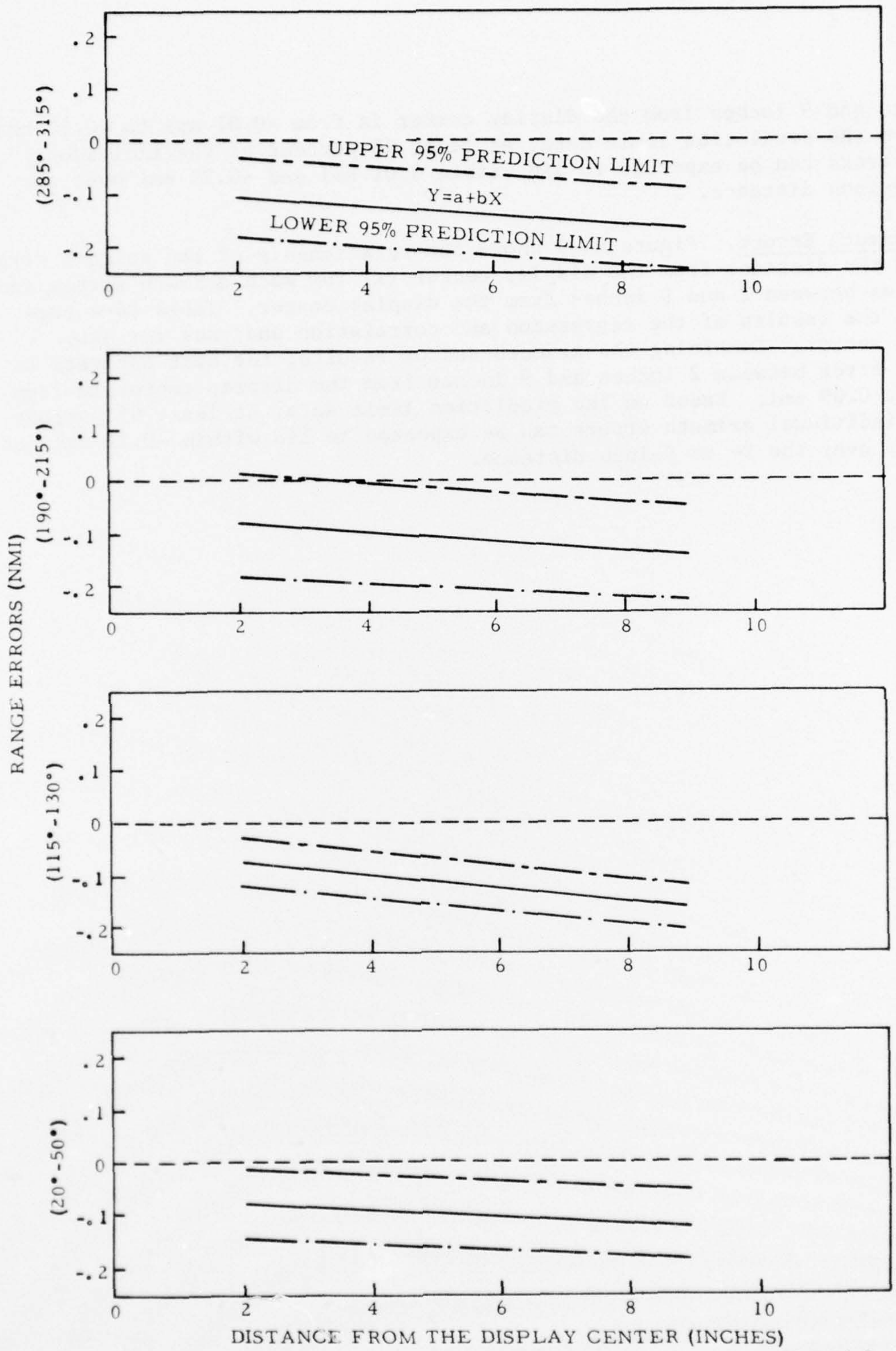

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FIGURE D4-8. RANGE ERROR VERSUS DISTANCE FROM THE DISPLAY CENTER

2 inches and 9 inches from the display center is from -0.07 nmi to -0.17 nmi. Based on the prediction limit data, at least 95 percent of the individual range errors can be expected to lie within 0.01 nmi and -0.25 nmi over the 2- to 9-inch distance.

Azimuth Errors. Figure D4-9 shows the relationship of the azimuth error (y) and the distance from the display center (x) for each azimuth sector and distances between 2 and 9 inches from the display center. Table D4-4 summarizes the results of the regression and correlation analyses for each azimuth sector. Combining the azimuth sector results, the best estimate of azimuth error between 2 inches and 9 inches from the display center is from -0.07 to 0.09 nmi. Based on the prediction limit data, at least 95 percent of the individual azimuth errors can be expected to lie within -0.16 nmi and 0.15 nmi over the 2- to 9-inch distance.

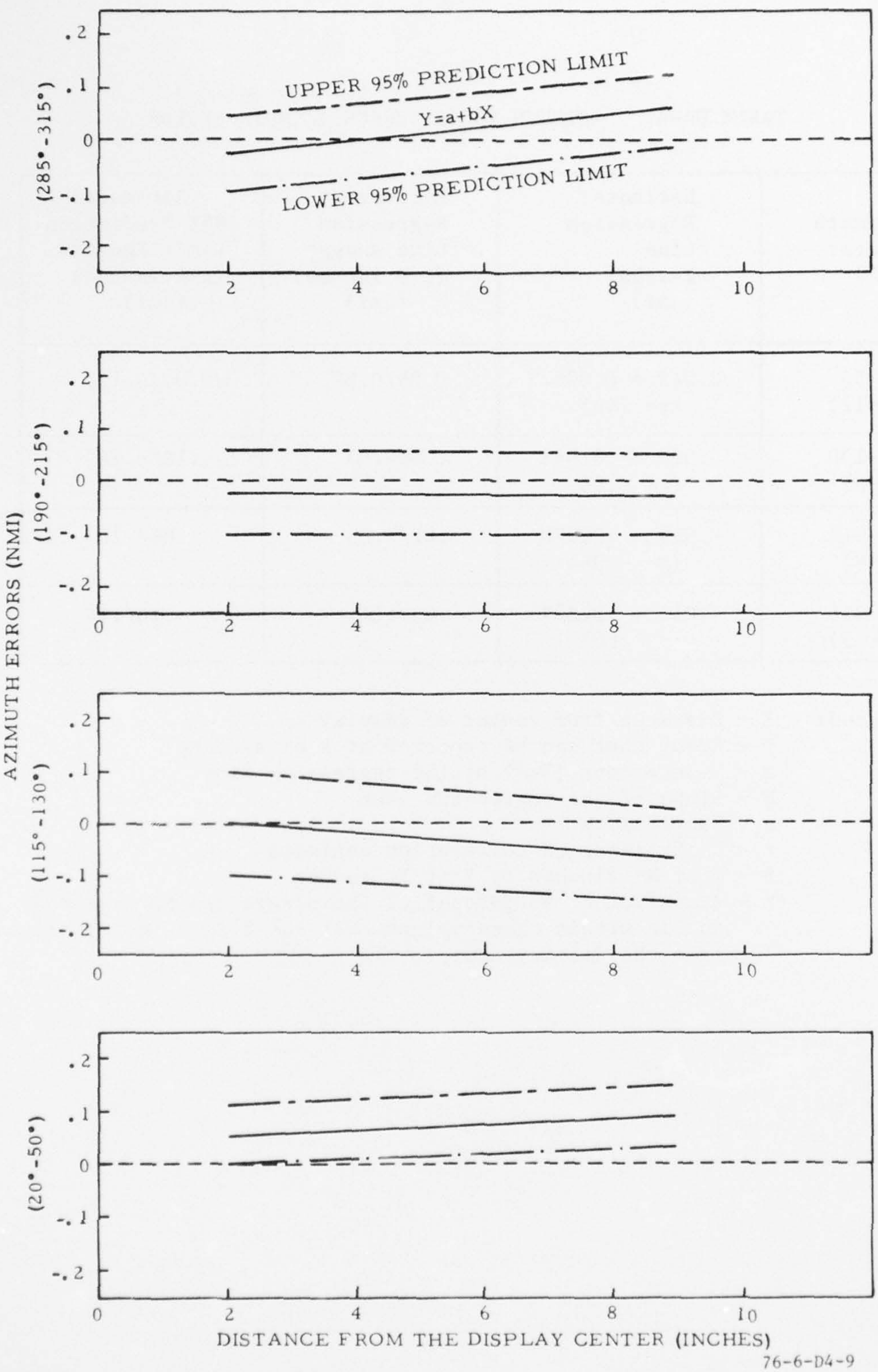

FIGURE D4-9. AZIMUTH ERROR VERSUS DISTANCE FROM THE DISPLAY CENTER

TABLE D4-4. AZIMUTH ERROR VERSUS AZIMUTH SECTOR

Azimuth Sector (°)	Estimated Regression Line Y=a+bX (nmi)	Estimated Regression Line Range* (2-9 inches) (nmi)	Estimated 95% Prediction Limit Range** (2-9 inches) (nmi)
20-50 (n=11)	0.043 + 0.0052X (r= .42)	0.05/0.09	-0.00/0.15
115-130 (n=6)	.022 - .0104X (r= -.68	.00/-.07	.10/-.16
190-215 (n=8)	-.019 - .0007X (r= -.06)	-.02/-.03	.06/.10
285-315 (n=15)	-.054 + .0128X (r= .60)	-.03/.06	-.10/.14

Legend:
X - Distance from center of display
Y - Error that can be expected at X on average
a - Y-Intercept (X=0) of the regression line
b - Slope of the regression line
n - Sample size
r - Coefficient of correlation estimate
* - Y at X= 2inches to Y at X=9inches
** - A minimum of 95 percent of the errors can be expected to lie within these values over the 2 to 9 inch distance from the display center.

CONCLUSIONS

1. Mean range and azimuth errors associated with the digital symbol of an ARTS III display, maintained in accordance with current field procedures, can be expected to fall within ±0.15 nmi from 2 inches to 9 inches from the display center. Individual range and azimuth errors over this same distance can be expected to fall within ±0.25 nmi, 95 percent of the time.

2. Depending on the range, range mark, and character size settings and the air traffic control specialist's (ATCS's) visual acuity, the errors given in paragraph 1 above may be significant. The overriding influence is considered to be the range setting. Going back to the nomograph given in figure D4-2, it can be seen that an error as high as 0.25 nmi represents less than 0.1 inches for range settings greater than 30 nmi. An error of 0.15 nmi would probably be undiscernable at the 30 nmi or greater range setting, since the associated distance would be 0.06 inches or less. It is interesting to note, that if the ATCS is off just 0.05 inches in estimating the digital symbol position, an error of 0.27 nmi would be made if the range setting was 60 nmi.

3. The results given in paragraph 1 above are considered satisfactory for use in estimating the overall ARTS III/ASR digital system error (project 142-177). Additional scope photo data reduction and analysis is not considered necessary.

APPENDIX D4A

SCOPE PHOTOGRAPH POSITION MEASUREMENT

The following procedures were followed to determine the range and azimuth of the digital symbol from the scope photographs:

1. An overlay was used to find the center of the display range marks which were photographed in their entirety during the test. Range marks of 2 nmi were selected for a display range of 14 nmi.

2. The Telereadex x and y wires were positioned to intersect at the center of the range marks. The x and y electronic counters were then set to zero.

3. The film, which was taken at a rate of one frame per second, was advanced until a frame of interest appeared. This frame was at least 2 seconds or frames following the time that the ARTS III reported the target position to the display. This time was allowed for updating of the digital symbol position.

4. To obtain a calibration or the number of counts per mile, the x and y wires were moved, first one, then the other, to each of the range marks immediately adjacent to the digital symbol. Several readings of the x and y counts were obtained in order to minimize reading error.

5. The x and y wires were then positioned to intersect the center of the digital symbol and the x and y counts were recorded. Again several readings were obtained to minimize reading error.

6. The target x and y counts were converted to x and y nautical-mile values using linear interpolations of the counts per nautical mile data and target count data derived in paragraphs 4 and 5 above, respectively.